12-2009

Stream Channel Stability and Channel Evolution in a Rapidly Urbanizing, Ridge-and-Valley Watershed, Beaver Creek, Knox County, Tennessee

Francis Bartholomew Keaney
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Francis Bartholomew Keaney entitled "Stream Channel Stability and Channel Evolution in a Rapidly Urbanizing, Ridge-and-Valley Watershed, Beaver Creek, Knox County, Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

Qiang He, Major Professor

We have read this thesis and recommend its acceptance:

Terry Miller, John Schwartz

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Francis Bartholomew Keaney
December 2009

Abstract

In Tennessee, sedimentation is among the leading causes of stream impairment. Excessive loads of alluvium are detrimental to the ecological health and human use of these resources. Sediments in streams have many sources, but there is evidence that stream bank erosion is a major contributing factor. Development and urbanization in a stream's watershed will have impacts on the concentration of stream sediment because the increase in the area covered by impervious surfaces, which reduces initial abstraction and retention times. This, in turn will increase the peak storm water discharge and sediment carrying capacity. If the stream channel cannot accommodate these flows, the form of its bed and banks will begin to adjust. These adjustments are described by the Channel Evolution Model developed by the USDA National Sedimentation Laboratory. The channel response will proceed through 6 stages, moving from a premodified condition through periods of degradation and periods of aggradation until a new, stable channel form is attained. Theoretically, it would be possible to use an evaluation of the stage of channel evolution at several sites along a disturbed stream to predict the response of the entire stream network. However, this can only happen in streams in which there are no controls on the ability of a channel to adjust freely. If this pattern were to hold true in the case of a rapidly developing watershed and could be detected by a relatively fast and easy assessment scheme, it would ease the difficulty of determining where to focus stream bank stabilization projects. In an effort to determine whether or not this was the case, a semi-quantitative Rapid Geomorphic Assessment, introduced by Andrew Simon, was used to evaluate

channel stability at sites throughout the watershed of Beaver Creek, a tributary of the Clinch River in Knox County. Instead of following a pattern of adjustment, or being controlled, per expectation, by channel gradient or upstream land use, statistical analysis showed that channel response appeared to be most heavily influenced by the ability of the channel material to resist erosion.

Table of Contents

List of Figures

List of Tables

List of Equations

Chapter 1 Introduction

In the state of Tennessee sedimentation is one of the leading causes of stream impairment. (TDEC, 2008; Parish, 2002) Sediment in streams has many sources, both from within the channel and from without, but there is evidence that stream bank erosion is a major contributing factor (Booth, 1990; Trimble, 1997). To combat stream bank erosion in developing watersheds, many municipalities around the country are attempting stream restoration projects aimed at returning streams to a more stable state.

While a certain amount of sediment being transported in streams is natural, excessive loads of alluvium have been shown to be detrimental to ecological health and human use of these resources. (Booth, 1997; Freeman, 2004). Sediment impacts stream ecology by degrading habitat. It can impair organisms' ability to locate food, destroys stream bed features used by organisms for reproduction and refuge and literally smother biota. It can affect humans by reducing the aesthetic and recreational value of the stream as well as increasing the treatment costs of water withdrawn from impacted streams (USEPA, 1999).

Land development and urbanization in a stream's watershed may cause elevated levels of in-stream sediment (Burges, et al, 1998; Price and Leigh, 2006). At the onset of development, sedimentation rates from surface water runoff will increase dramatically, because construction activities expose bare soil to rainfall. Once construction is complete the influx of sediment from the watershed tapers off, but peak stormwater runoff rates increase due to the larger impervious surfaces. Increased area covered by impervious surfaces reduces initial abstraction and retention times. If the stream channel cannot accommodate increased flow frequency and volumes, its bed and banks will begin to adjust (Rhodes, 1995).

These channel adjustments are described in the Channel Evolution Model (Simon, 1986). The channel's response to disturbance will proceed through 6 stages, moving from a premodified condition through periods of degradation and periods of aggradation until a new, stable channel form is attained. Adjustment begins as material on the channel bed is entrained in the flow and moved downstream by the excess stream power. This downcutting results in higher, steeper, less stable banks. When downcutting proceeds far enough, banks begin to fail, resulting in widening of the channel.

According to the model, channel adjustment will follow a predictable pattern, responding differently upstream and downstream of the area of maximum disturbance. Theoretically, it would be possible to use an evaluation of the stage of channel evolution at several sites along a disturbed stream to predict the response of the entire stream network in the watershed (Simon and Downs, 1995). However, this can only happen in streams in which "(1) there is no local bedrock control of bed-level, (2) overadjustment and secondary response are active processes, (3) the bed and banks are free to adjust to imposed changes, and (4) successive stages of evolution are not interrupted by other disturbances" (Simon, 1989).

The aim of this study was to investigate whether or not there were observable, system-wide patterns in the response of stream channels in the Ridge and Valley ecoregion to the urbanization of their watersheds, or whether channel stability at any given reach is a function of the local characteristics of a reach, specifically slope, bed material, and degree of catchment urbanization. The primary diagnostic tool used in these evaluations was the Rapid Geomorphic Assessment (Simon and Downs, 1995). The RGA requires the user to quantify several field-based observations of reach-scale channel stability criteria and assign the site an overall stability score.

Chapter 2 Literature Review

2.1 Physical process of fluvial erosion:

A large body of research has been created over the past century detailing the physical processes by which stream flows erode channel beds and banks. As water flows over a particle resting on the stream bed, it creates areas of high velocity and low pressure. Given sufficient energy, flow rates are reached that are high enough to create the necessary amounts of drag for the lift forces to overcome the force of gravity acting upon a particle. Once the particle is lifted off the bed, it becomes entrained in the flow. For small enough particles cohesive forces become important, causing particles to stick together which increases their resistance to erosion.

The aggregate effects of individual particle erosion are bed and bank erosion. Bed erosion results in down cutting, leaving an artificially incised channel. Bank erosion proceeds through several different pathways. The simplest, fluvial erosion, involves bank material being entrained in the flow and moved downstream. Mass wasting occurs when the angle of the stream bank exceeds a critical shear angle and large areas of the bank begin to slough downward towards the stream. The critical shear angle is dependent on many factors, including bank material, vegetation and root density, soil moisture conditions and weather related subaerial processes. Bed and bank erosion work in concert to enlarge stream channels to accommodate new flow regimes. As the bed and lower banks erode through fluvial process, bank angles are increased until they exceed the critical shear angle and mass wasting occurs. The sloughed blocks of bank material are then exposed to fluvial erosion processes.

2.2 Fluvial erosion and mass wasting

According to Rhoads (1995), stream power is "the rate of work or loss of potential energy that occurs as water moves along an energy gradient." It is defined as

Equation 1 – Rhoads Stream Power Equation

$$P = \int \gamma Q S_e \ dx$$

Where P is stream power, Q is discharge, S_e is the energy gradient and x is distance along the reach. Energy gradient is closely related to channel bed gradient, but accounts for changes in velocity across depth and downstream distance. A portion of this energy is always used to transport sediment particles. In a stable stream channel, the amount of stream power will be in equilibrium with the amount of sediment available for transport. That is, the amount of sediment transported from upstream and deposited along a reach will be equal, over time, to the amount of sediment entrained and moved downstream from the reach. In an aggrading channel, there will be more sediment than can be transported by the stream power provided, resulting in deposition. In a degrading channel, more stream power will be present than sediment supply, which will result in net erosion.

As a way to conceptualize the relationship between the erosive force or a river's discharge and its sediment supply, Lane (1955) proposed a "very general expression"

Equation 2 – Lane's Relationship

$$Q_s\, d \sim Q_w S$$

In which Q_s is the quantity of sediment, d is the bed-load sediment's particle diameter size, Q_w is the water flow rate and S is the slope of the stream. Degradation will be caused either by a decrease in the magnitude of the factors on left or an increase in the magnitude of the factors on the right. Likewise, aggradation will be caused by an increase in the magnitude of the factors on the left, or a decrease in the magnitude of the factors on the right. One of the basic tenants of fluvial geomorphology is that this relationship will tend towards equilibrium such that when any factor in the relationship is changed, at least one of the other factors will change in such a way as to restore that equilibrium.

The right side of this relationship is equivalent to the definition of stream power given by Leopold (1964):

Equation 3 – Leopold's Stream Power Equation

$$\Omega = \gamma Q S$$

In which Ω is the total stream power, γ is the specific weight of water, Q is the water flow rate and S is the channel slope. For the equivalence to hold, the specific weight of water is assumed to be constant. Thus, when stream power increases, degradation it results in channel degradation as sediment is eroded.

In the case of an urbanizing watershed, the most common long-term change to the Lane relationship is an increase in the magnitude of Q_w. This leaves the stream's slope unstably high, so channel-bed degradation is likely to begin, so as to allow the relationship to regain equilibrium. Q_s is also likely to decrease, since more impervious surfaces in the watershed lead to less sediment being washed into the stream, and d is likely to increase, as smaller particle sizes are washed away in the degradation process.

2.3 Effects of roots and vegetation:

Soil scientists have recognized for some time the beneficial effects of root systems on soil stability. Recent studies have aimed to quantify their effects on stream banks. Simon and Collison (2002) found that root networks of common riparian tree and grass species provide both mechanical and hydrological support for stream banks. Mechanically, the root networks add tensile strength to soils that would otherwise lack it, which increases the effective shear angle of the mass failure plane. Hydrologically, the plants transpire water which decreases the positive pore pressure of the soil, increasing cohesive strength.

Evidence shows that stabilizing effects are different for woody and non-woody vegetation (Wynn, 2006). Non-woody plants growing on the bank itself serve to armor it and better prevent fluvial erosion. Woody plants in the riparian zone provide better stabilization in high velocity conditions, such as the outside of meander bends or during floods, and can better protect against mass wasting.

2.4 Subaerial processes:

Especially in channels whose banks are composed of very fine particles, or don't have steep bank angles, subaerial processes can assume an important role in bank erosion. (Prosser, 2000) The most important of these involve the actions of water in the bank. During cold weather, the water freezes and expands. This disrupts the cohesive effects of soil moisture and displaces clumps of soil particles. In hot, dry weather, enough soil moisture can evaporate so as to cause the soil to lose enough mass that it begins to contract. This causes flakes to form near the surface. Combined with the loss of cohesion brought about by the loss of water, the flakes are more easily removed by the next high flow. These processes alone can account for up to 181 mm/year of stream bank retreat (Couper, 2003).

In soils with larger particle sizes, soil moisture has a destabilizing effect. As stream stage rises, water fills the inter-particle spaces, reducing friction and fluidizing the bank. This leads to instability which can result in collapse.

2.5 Effects of urbanization

The effects of urbanization on channel stability have been under investigation for decades. The topic is of interest for practical as well as academic reasons, since a rapid increase in channel instability can affect property, safety and structures (especially bridges and other channel crossings). Additionally, the sediments eroded can create problems for downstream habitats and water treatment facilities. Several methods were used in all of the studies. Either multiple watersheds representing different stages of development were compared at one time (Klein 1979), or a single reach that passes through areas experiencing different degrees of urbanization was monitored at different sites (Obermerho, 1992).

The primary cause of channel instability due to urbanization is the increase in peak flow rate caused by the decrease in detention time, which is in turn caused by the change in land use. It is often assumed that this change is caused mostly by an increase in the percentage of a watershed covered by impervious surfaces, but some research suggests that a change from one type of pervious surface to another (say, from deciduous forest to tended grass lawns) can have just has high an effect (Burges, 1998).

Several researchers have sought to define the correlation between the degree of urbanization and the degree of channel instability. Their investigations have shown that while the two processes do have a causational connection, there is no direct linear relationship that can be applied in general to all channels. In fact, the degree of urbanization is sometimes not the controlling factor. Rates of change in channel stability also are affected by local geography, sediment type and the presence of buffer strips of riparian vegetation, among other factors (Arnold, et al, 1982). However, in any one channel, such a relationship may exist (Klein, 1979). Over time, after the changes to land use have ceased, streams will typically find a new equilibrium between channel shape and flow rates.

It is inevitable that, in the absence of protective structures, stream channels will be modified by the changing flows brought on by urbanization. Most frequently, the increase in sediment carrying capacity due to increased peak flow rates will more than offset any increase in sediment yielded by runoff. This will cause the channel to enlarge as bank and bed material are eroded away. A study in the Piedmont region of Maryland found that eroded sediment did not begin to influence stream quality until 12% of the watershed had been covered with impervious surfaces (Obermerho, 1992). However, due to differences in other basin characteristics, these results can not accurately be used for other watersheds or even the same watershed after a period of several years (Henshaw and Booth, 2000).

The importance of channel erosion (as compared to surface erosion) is demonstrated by Trimble (1997). In this study, stream bank profile measurement, land use (based on aerial photographs) and sediment delivery monitoring were used to quantify the amount of sediment load for which channel erosion was responsible in a developing watershed in southern California near San Diego. The results of this study showed that upwards of 2/3rds of sediment delivery was due to channel erosion (The author points out that because of the sandy nature of the sediment, the suspended sediment measurement stations probably underestimated bed transport loads. He estimates that the actual contribution of channel erosion to sediment load is closer to 50%.)

The type of material through which the channel flows can have a profound effect on erosion rates. In Henshaw and Booth (2005), a study of various watersheds in Washington State, it was shown that a stream flowing through soils made of glacial till, yet subjected to no significant development showed much more bank instability (and therefore erosion potential) than a stream flowing through fossilized peat deposits in a basin that had recently experienced large amounts of development. They compared 10 straight channel, plane-bed sections along four creeks which were selected because extensive historical records, including rainfall, stream gages and previous site surveys, were available. Their primary metrics were stream profiles and a quantitative technique for the rapid assessment of channel stability. Their results showed urbanization having a “coarse effect” on the degree instability. They concluded that urbanization merely provided a situation in which the natural causes of hydrologic change were amplified.

The same study showed that, for the reaches surveyed, several decades would be enough time for the channels to find a new equilibrium. This was in contrast with the prevailing assumption at the time that channel instability would continue for the foreseeable future, based on the rapid channel stability assessment technique.

A separate study (Obermerho, 1992) sought to measure how undeveloped stretches downstream of developed areas responded to development. This study was limited by the fact that it considered only 10 cross sections along one stream and did not take into account how the channel responded over time. It compared the growth of channel cross section upstream of the developed area to that experienced by the channel downstream of the developed area. It concluded that, in this instance, there was no downstream propagation of channel disturbance due to development, possibly because wide floodplains were able to absorb any excess stream power in the downstream stretches. By using only channel cross sections, this study measured the channels’ transport capacity, but did not consider erosive forces or the bed and bank material’s resistance to erosion.

2.6 Channel Evolution Model

There is currently debate over whether form-based or process-based geomorphic assessments are better applicable to stability assessment. (Rosgen, 1994; Simon, Doyle, et. al., 2007) A popular example of a form-based assessment is David Rogen's widely practiced technique which requires the assessor to compare the morphologically active stream reach in question to a stable reach of a stream that flows through similar conditions. In this assessment type, a stream is fitted into a category based on channel type, bed material and slope. For categories assumed to be "stable", forms and restoration projects aim to fulfill those characteristics. This form-based assessment was developed to describe naturally evolving streams. Considering the ways in which human activity can alter the energy inputs that govern channel morphology, this type of assessment may not accurately determine the current stream type, much less predict its future development. (Simon, et al., 2007) Other methods have been developed to assess channel stability based on the underlying processes that influence geomorphic change (Niezgoda, 2005).

One process-based method was used in this study. Andrew Simon's Rapid Geomorphic Assessment (RGA), first proposed in Simon (1989), describes a channel's response to disturbance as a progression through six distinct stages of evolution. A final stability score is determined by assigning points to various stability indicators. Simon and Downs (1995) found that for alluvial channels (in West Tennessee, at least), a RGA score of 20 or higher could be considered "critically unstable" and would pose a threat to adjacent property. This critical score was calibrated through on-site evaluations and the experience of local personnel and could vary for channels in different areas with different conditions (Simon .

The six stages of channel evolution, as laid out in Simon and Hupp (1986) and elaborated upon in Simon (1989) and Simon and Downs (1995) are:

Stage 1: Premodified. In this undisturbed stage, the channel's form is the result of natural fluvial processes as influenced by natural land use. This form is characterized by stable, alternating channel bars, convex top banks with vegetation down to the high flow stage line and straight or meandering channel plans. The fluvial processes which dominate are mild aggradation and basal erosion and deposition at the outside and inside of bends, respectively.

Stage 2: Constructed. In the original description, this stage referred specifically to channels that had been artificially straightened to behave more like a trapezoidal flume than a natural stream. Typically, the channel was made linear, and the vegetation was removed. A channel in this stage would represent the Area of Maximum Disturbance, so for the purposes of this study, this stage was also used to describe reaches that were in the process of being disturbed in other ways, such as by nearby construction.

Stage 3: Degradation. This stage represents the initial geomorphological response to disturbance. The disturbed channel is in disequilibrium so it can neither accommodate the new stream power nor replace eroded material with upstream sediment input. As such, the alternating bar structure, channel bed and bank toes begin to erode.

Stage 4: Threshold. Also called “Degradation and Widening”, this stage is characterized by banks that, because of bed and toe erosion, have exceeded their critical bank height. In this unstable state, the banks are vulnerable to sloughing, slab and pop-out failures, so mass wasting is the dominant erosion process. Herbaceous riparian plants are not present on the banks and nearby trees have tilted towards or fallen into the channel.

Stage 5: Aggradation. As degradation proceeds upstream the newly eroding reaches will supply enough sediment to allow aggradation to take place at previously degrading downstream reaches. Fine sediment and sand will be present in pools and along the bank toe. Because unstable banks have already failed, bank angles are less steep.

Stage 6: Restabilization. The channel in this stage is characterized by a return of natural bedforms and stable channel banks. The stream plan will return to a meandering pattern. Banks will have retreated to a stable angle and will have been recolonized by non-woody vegetation.

Deggradation or aggradation processes are initiated in “areas of maximum disturbance” (AMD) (Simon, 1989) which act as “knickpoints” or “knickzones” (relatively short stretches of river with relatively high slopes, in the case of sand-bed rivers) and will cause longitudinal migration of bed level, proceeding upstream and downstream, unless interrupted by a gradient control, or another aggradational or degradational process. Galay (1983), discussing only degradation, saw changes in channel slope as the primary instigator of these process. He split degradation into two types based on the direction that the knickpoint travels along the stream; Upstream Degradation and Downstream Degradation. Upstream degradation is the result of a disturbance which increase slope, such as dredging and excavation, or the artificial straightening of a channel. Downstream degradation is the product of a decrease in channel slope such as the decrease in sediment supply and resultant erosion downstream of dams or a major change in the ability of bed material to resist erosion, such as gravel mining. He saw upstream degradation as a faster process, due to the increase in available stream power, and will take place over a scale of years to decades, whereas downstream degradation requires much more gradual reduction of slope, which would take place over a time frame of at least the decadal scale.

Chapter 3 Objective

Historically, much research has been conducted to investigate the causes and small scale processes of stream channel erosion. Recently, attention has been paid to channel instability as a watershed scale problem. Prior studies have shown that, in rural and agricultural settings, future stability conditions of a stream reach can be predicted by performing an evaluation of the current condition of disturbed streams. The Channel Evolution model allows this prediction by describing the stages through which disturbed channels will progress.

If the Channel Evolution Model also described the evolution of disturbed channels in urbanizing watersheds, it could help managers to mitigate the detrimental effects of development. However, due to the interruption of knickpoint migration caused by stream channel controls and the continuous nature of disturbances caused by development, the model probably does not apply in urbanizing areas.

This study aims to evaluate whether the Channel Evolution Model can be used to describe the adjustment processes of streams disturbed by urbanization. The Simon Rapid Geomorphic Assessment will be used assess channel stability throughout the watershed. Additional analysis will be performed to determine whether factors connected to urbanization, such as the percentage of a catchment that has undergone development or the amount of impervious surfaces in a catchment, will affect the channel stability index for a given reach.

Chapter 4 Study Area

The Beaver Creek Watershed has an area of 223 km2 (86 mi2) and is located in northeast Knox County, Tennessee. It is roughly rectangular, about 75 km (mi) long by 3 km (mi) wide. Beaver Creek, which is a 3rd order stream (by the Strahler method) generally flows from northeast to southwest, confined by Copper Ridge to the north and Black Oak Ridge to the south. Beaver Ridge is contained entirely within the watershed, and acts as a boundary for many of the subwatersheds. The farthest headwaters originate in Gibbs and descend a total of 85 m (Parish, 2002) to the confluence with the Clinch River, near Solway. The stream network does not experience any dramatic changes in elevation and thus is characterized by mild gradients, as evidenced by a valley slope of .0013% (Parish, 2002). The region has a humid subtropical climate with regular periods of below freezing temperatures in the winter.

Large scale modifications to land use began when suitable areas were cleared of forest for agriculture and timber. More recently, beginning around the 1950s, the area began to undergo suburbanization, which intensified notably in the mid 1980’s and continues to the present day (Ogden, 2000a). As shown in Figure 1 and Figure 2, development is most intense along major highway corridors and in areas closer to downtown Knoxville. It is less intense on steep ridge slopes. Rapid suburban development is expected to continue, aided by road-widening projects and the continued growth in the American Southeast (Ogden, 2000b).

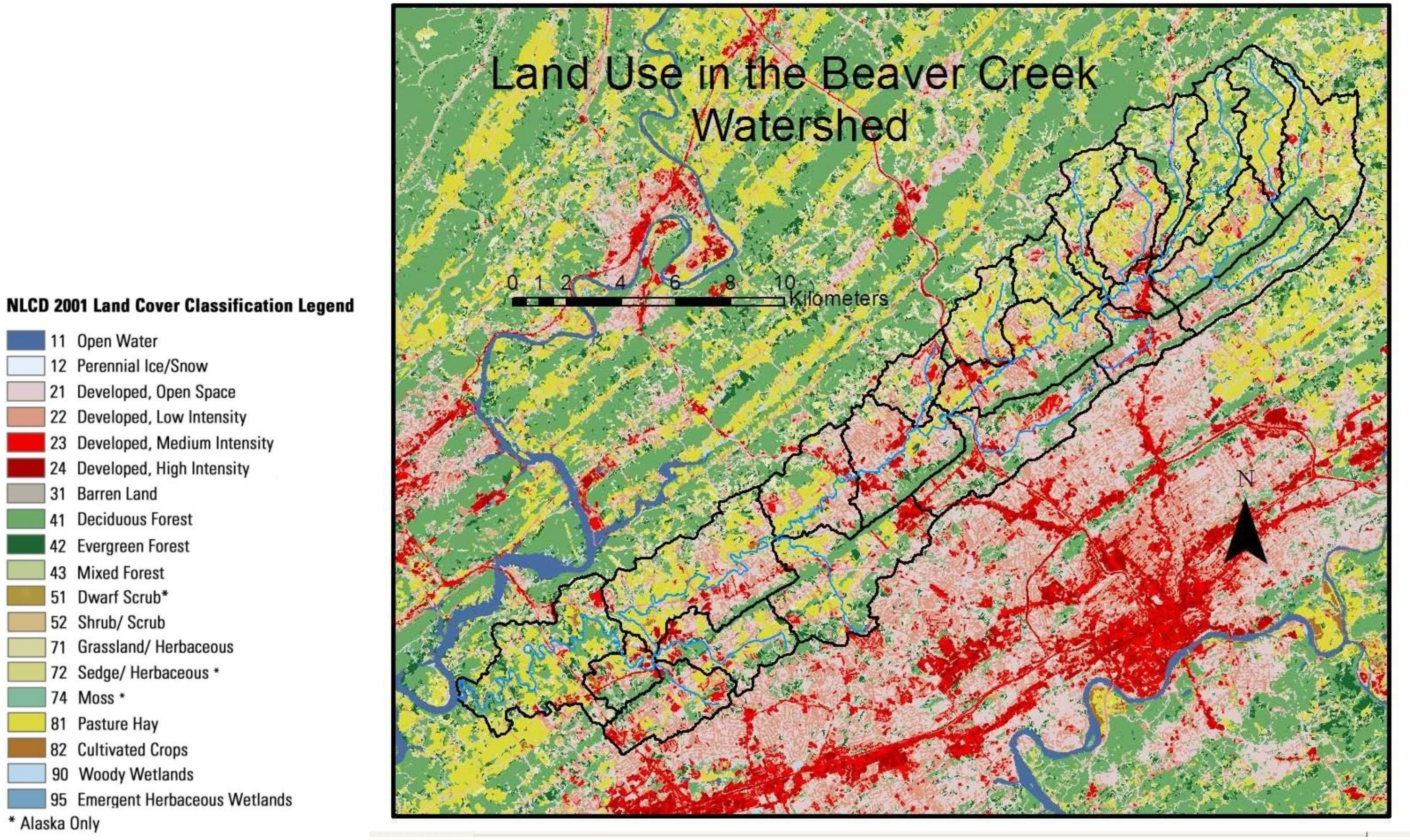


Figure 1 - 2001 NLCD Land Cover in Beaver Creek Watershed and Surrounding Areas

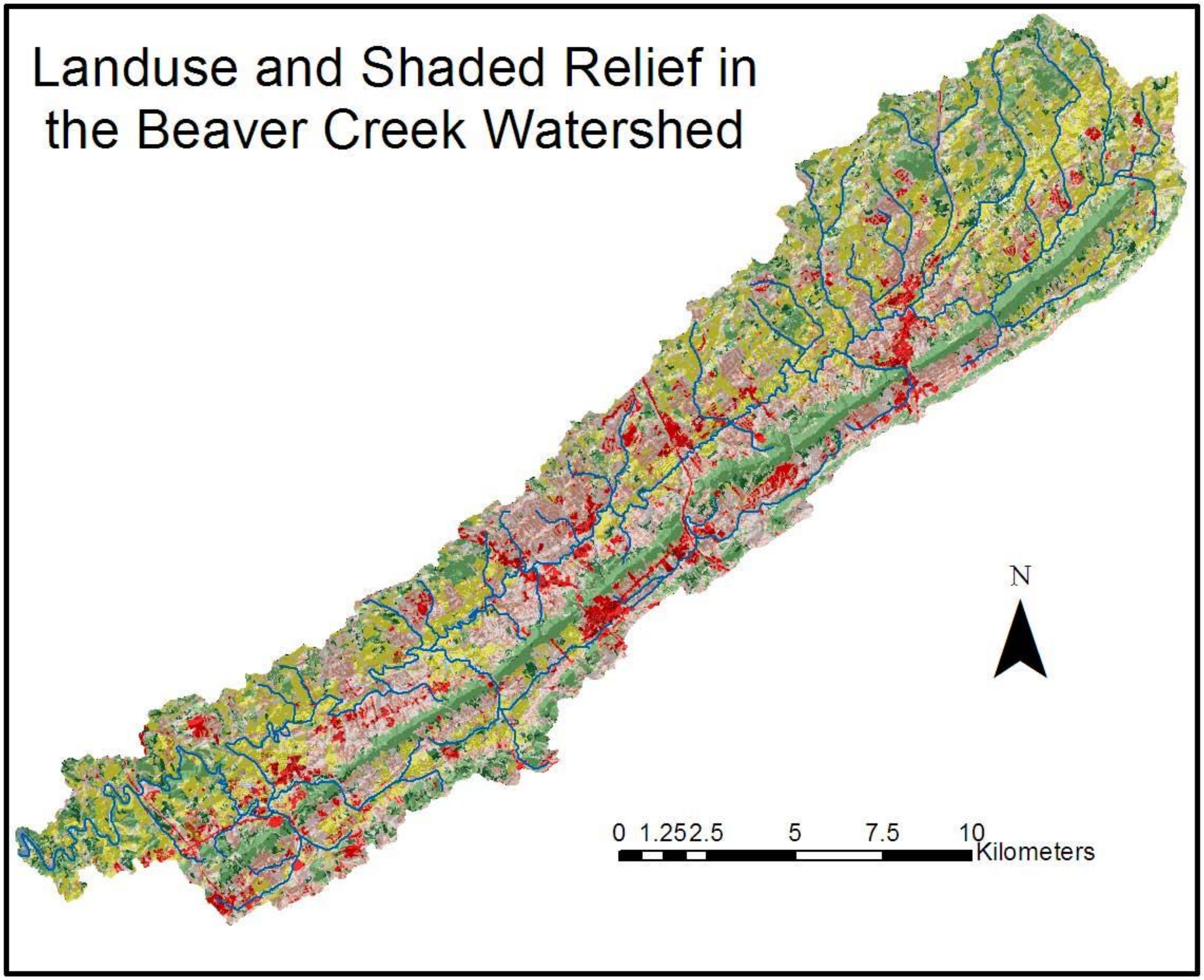


Figure 2 - 2001 NLCD Land Use and Shaded Relief in the Beaver Creek Watershed

The Beaver Creek watershed contains 83.86 miles of streams listed on the USEPA 2008 303.d list of polluted surface waters, including 69.1 miles listed for habitat loss or “loss of biological integrity due to siltation”.

According to the United States Environmental Protection Agency, the Ridge and Valley Ecoregion is described as follows:

> “This northeast-southwest trending, relatively low-lying, but diverse ecoregion is sandwiched between generally higher, more rugged mountainous regions with greater forest cover. As a result of extreme folding and faulting events, the region’s roughly parallel ridges and valleys have a variety of widths, heights, and geologic materials, including limestone, dolomite, shale, siltstone, sandstone, chert, mudstone, and marble. Springs and caves are relatively numerous. Present-day forests cover about 50% of the region. The ecoregion has a diversity of aquatic habitats and species of fish.” (USEPA, 2002)

Another complicating feature of the Beaver Creek watershed is the presence of karst topography. A total of 11.19 square kilometers of the watershed drains into sinkholes, with the majority of that area being to the north of Beaver Creek (Ogden, 2000b). Based on field observations, this caused several tributary streams, specifically Allen Branch, North Fork and Mill Branch to alternate between surface and subterranean flow. Significant stretches of these streams’ channels were dry during normal low-flow conditions. Since this would greatly disrupt the migration of knickzones at the scales of interest in this study, these streams were mostly ignored.

For the purposes of this study, the watershed was divided into the sub-watersheds that drained the tributary streams. This allowed for the level of development in a variety of small catchments to be analyzed separately. These sub-watersheds are shown in the context of the entire Beaver Creek watershed in Figure 3.

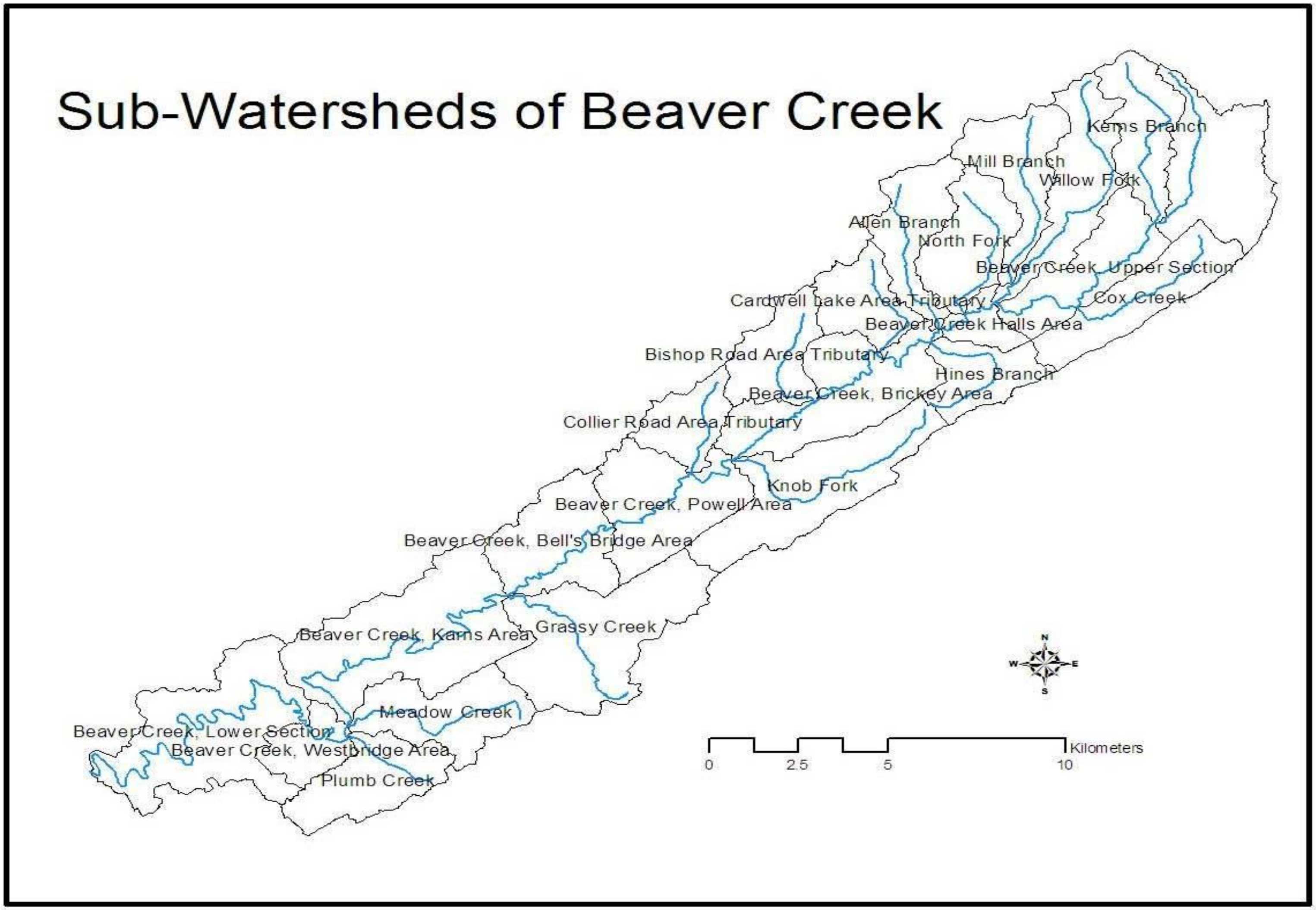


Figure 3 - Sub-Watersheds of the Beaver Creek Watershed

Chapter 5 Methods

5.1 Field Assessments:

Three key metrics were obtained for each site. These were a Channel Stability Index, water surface slope and a Modified Wolman Pebble Count. If the bed material at the site was composed entirely of bedrock or of sand or smaller particles, a pebble count was not performed. The latitude and longitude for each site were recorded with a Global Positioning System receiver accurate to 5 meters.

The Rapid Geomorphic Assessment used in this study was developed by Andrew Simon, of the National Sedimentation Laboratory in Oxford, MS, as a tool to allow a quick evaluation of reach-scale stream bank stability to be made in the field by personnel with relatively little training.

RGA sites were selected using a detailed map of all streams, swales and water conveyances in the Beaver Creek Watershed that was provided by the Knox County Stormwater Department. Channelization was inferred by visual estimation of sinuosity. An effort was made to ensure that sites were somewhat evenly spaced along the length of the stream, to provide data for sites ranging from the headwaters to mouth. Field visits were made to determine whether access to the stream was available and whether there existed a baseflow adequate to perform an RGA.

The Rapid Geomorphic Assessment ranked stream channel stability on a scale from 0 to 36, as measured by a series of 9 quantitative and semi-qualitative metrics. The scores assigned to each metric were summed to obtain the total RGA score. This total score is also termed the “Channel Stability Index”. The nine metrics are:

1. Primary bed material. A score between 0 and 4 was given based on the stability of the bed material. 0 was given to bedrock, 1 to boulder/cobble, 2 to gravel, 3 to sand and 4 to silt/clay.

2. Bed/bank protection. A score of 1 was given if no bed or bank protection was present. Two points were given if one bank was protected and 3 points if both banks were. Thus, if a reach had an unprotected bed and two banks protected, the score would be 4. If the bed was protected, the score would be 3.

3. Degree of incision. A score of 0 to 4 was awarded based on the ratio of the bank height (from the toe to the top bank) to the depth of flow at the deepest part of the reach. 0-10% incision was scored 4, 11-25% incision was scored 3, 26-50% incision was scored 2, 51-75% incision was scored 1 and 76-100% incision was scored 4.

4. Degree of constriction. A score of 0 to 4 was awarded based on the ratio of channel width at the head of the reach to the width at the bottom of the reach. 0-10% incision was scored 0, 11-25% constriction was scored 1, 26-50% constriction was scored 2, 51-75% constriction was scored 3 and 76-100% constriction was scored 4.

5. Stream Bank Erosion. Each bank was considered separately. If no erosion was present, it was scored 0. If fluvial erosion was the dominant process, it was scored 1. If mass wasting was the dominant process, it was scored 2.

6. Stream bank instability. If mass wasting was present, whether or not it was the dominant process, the percentage of each bank in the reach on which it appeared was assessed. 0-10% failing was scored 0, 11-25% failing was scored 0.5, 26-50% failing was scored 1, 51-75% failing was scored 1.5 and 76-100% failing was scored 2. This assessment was performed separately for each bank.

7. Established riparian woody-vegetative cover. The percentage of each bank on which woody vegetation was present was considered separately. 0-10% covered was scored 2, 11-25% covered was scored 1.5, 26-50% covered was scored 1, 51-75% covered was scored 0.5 and 76-100% covered was scored 0.

8. Occurrence of bank accretion. The percentage of each bank upon which fluvial deposition was present was considered separately. 0-10% covered was scored 2, 11-25% covered was scored 1.5, 26-50% covered was scored 1, 51-75% covered was scored 0.5 and 76-100% covered was scored 0.

9. Stage of channel evolution. A score between 0 and 4 was awarded based on the stage of channel evolution. Stage 1 was scored 0, Stage 2 was scored 1, Stage 3 was scored 2, Stage 4 was scored 4, Stage 5 was scored 3 and Stage six was scored 1.5.

Slope was measured with a Pentax AL-M4c Autolevel. Frequently, the reach of interest was less than or equal to 100 ft in length, so the slope was measured from points 50 ft upstream and 50 ft downstream of the level, in order to ease calculations. At certain downstream sites, longer reaches were surveyed, to account for the fact that a reach length of six to ten channel widths would be longer than 100 ft. In these instances, the measurements were corrected to provide a percent slope.

The pebble count procedure was modified from Wolman (1954). A fiberglass tape measure was stretched across a riffle to such a distance that 50 feet were covered (since most reaches would not accommodate a 50ft length of tape directly across the stream, several transects across the same riffle were often used.) Every 0.5 ft the operator lowered his finger straight down and selected the first object he touched. If it was a pebble between 2 mm and 125mm, its size was recorded. If it was a finer particle, it was categorized as clay, silt or sand, depending on feel. If it was larger, it was categorized as cobble, boulder or bedrock, based on visual estimation.

High resolution digital photographs were taken showing the upstream and downstream views of each assessment site. Photographs of bank cross section were taken as necessary, if an interesting feature warranted them.

5.2 Spatial analysis:

A digital elevation model of the Beaver Creek watershed area was obtained from the United States Geological Survey National Map Seamless Server. The hydrology toolset incorporated in ESRI's ArcMap 9.3 was used to delineate flow paths as a raster image based on flow accumulation. The latitude / longitude location of each geomorphic assessment site was then plotted onto this map as a point shapefile. The points representing the assessment sites were fitted to the flow accumulation raster so that upstream catchments could be developed. The degree of urbanization in each catchment was determined by overlaying the map with a layer containing the NLCD 2001 Land Cover Classification. "Urbanization" was defined as areas that were labeled 21: Developed, Open Space; 22: Developed, Low Intensity; 23: Developed, Medium Intensity and 24: Developed, High Intensity. The percentage of each catchment that was forested was determined by summing the total of 41: Deciduous Forest and 42: Evergreen Forest. Due to the difficulty of combining the NCLD 2001 Impervious Surfaces raster with the watershed rasters, the area of impervious surfaces was estimated using the "averaging-by-land-use" system used previously in Knox County in the Second Creek watershed and developed by Camp, Dresser & McKee, an environmental consulting firm (Castle, 1996).

5.3 Statistical Analysis:

The scores for each metric at each site, as well as the total Rapid Geomorphic Assessment score, the slope, the d50 of the pebble count, the percentage of developed land in the local upstream area and total upstream catchment, the percentage of each catchment that was forested and the percentage of each catchment that was covered by impervious surfaces were used as the input for multivariate statistical analysis using SAS's JMP 7.0.1. The dataset was input as 15 independent and semi-dependent variables and 1 dependent variable. The overall RGA score was taken to be the dependent variable in most analyses, although most of the metrics used to compute the RGA are also controlled, to varying extents, by the same processes as overall channel stability. In particular, the Stage of Channel Evolution, percent of bank failing, degree of incision, bed material and presence of bank accretion were the variables that should have most closely correlated with the overall stability score. Correlations between these variables would not convey information as useful as those between metrics that gave approximations of the processes that control stream channel morphology.

Water surface slope was expected to be a controlling factor for incision, bank accretion, and bed particle size, so these factors were analyzed independently. The presence of vegetation on stream banks was expected to have a strong influence on bank stability, and the RGA allows for each bank to be assessed separately, so the scores for overall stream bank woody vegetation and percentage of stream banks failing, as well as the scores for the left and right banks for both those metrics were analyzed.

Chapter 6 Results

6.1 Plumb Creek

Five sites in the Plumb Creek watershed were assessed completely. Near the midpoint of its length, Plumb creek splits into two branches. Sites 20 and 19 are below the confluence of the two branches, sites 21 and 18 are on the southern branch and site 22 is on the northern branch. Sites are listed from downstream to upstream. In addition, three sites were assessed with the RGA, but no slope or pebble count measurements were taken. These sites are marked with letter identifiers, complete sites are marked with numbered identifiers. Of the study area (the watershed upstream of the farthest downstream study site), 63.3% has undergone development, 19.56% is covered by impervious surfaces and 22.92% remains forested. It is included in the High Development group of watersheds. Figure 4 shows the spatial relationship of the Stage of Chanel Evolution in the watershed, and Figure 5 shows the RGA scores at each site.

Several watershed characteristics and RGA metrics are presented in Tables 1 and 2. Only one site (#18) in the Plumb Creek watershed achieved an RGA score above 20, though three others (#19, #21 and #22) were very close. The remaining site was assigned a score of 9.5, one of the lowest in the study.

As shown in Tables 1 and 2 and Figure 4, there was not apparent that the stage of channel evolution at any given site was responding to any particular area of maximum disturbance, even though the sites were within 1 km or each other.

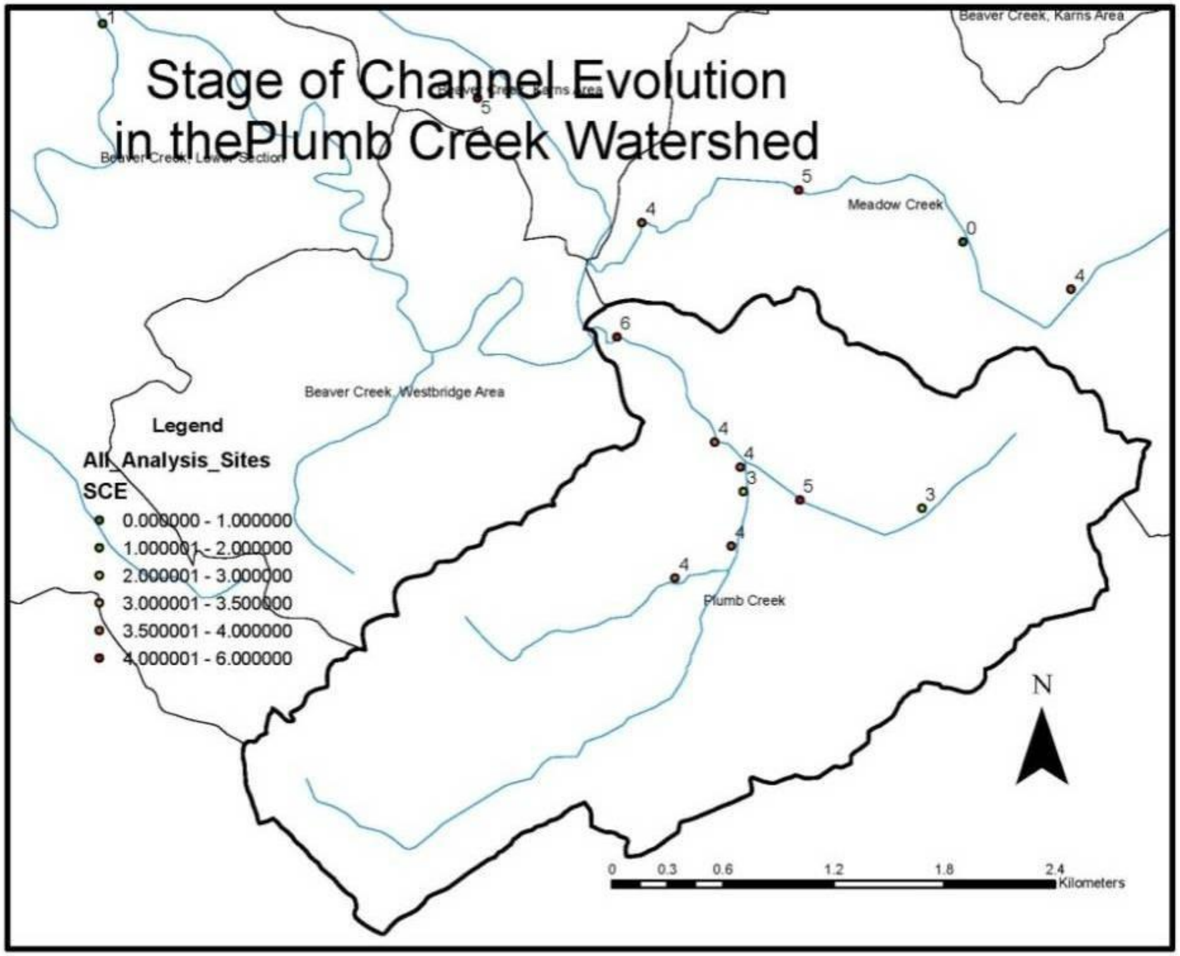


Figure 4 - Stages of Channel Evolution in the Plumb Creek Watershed

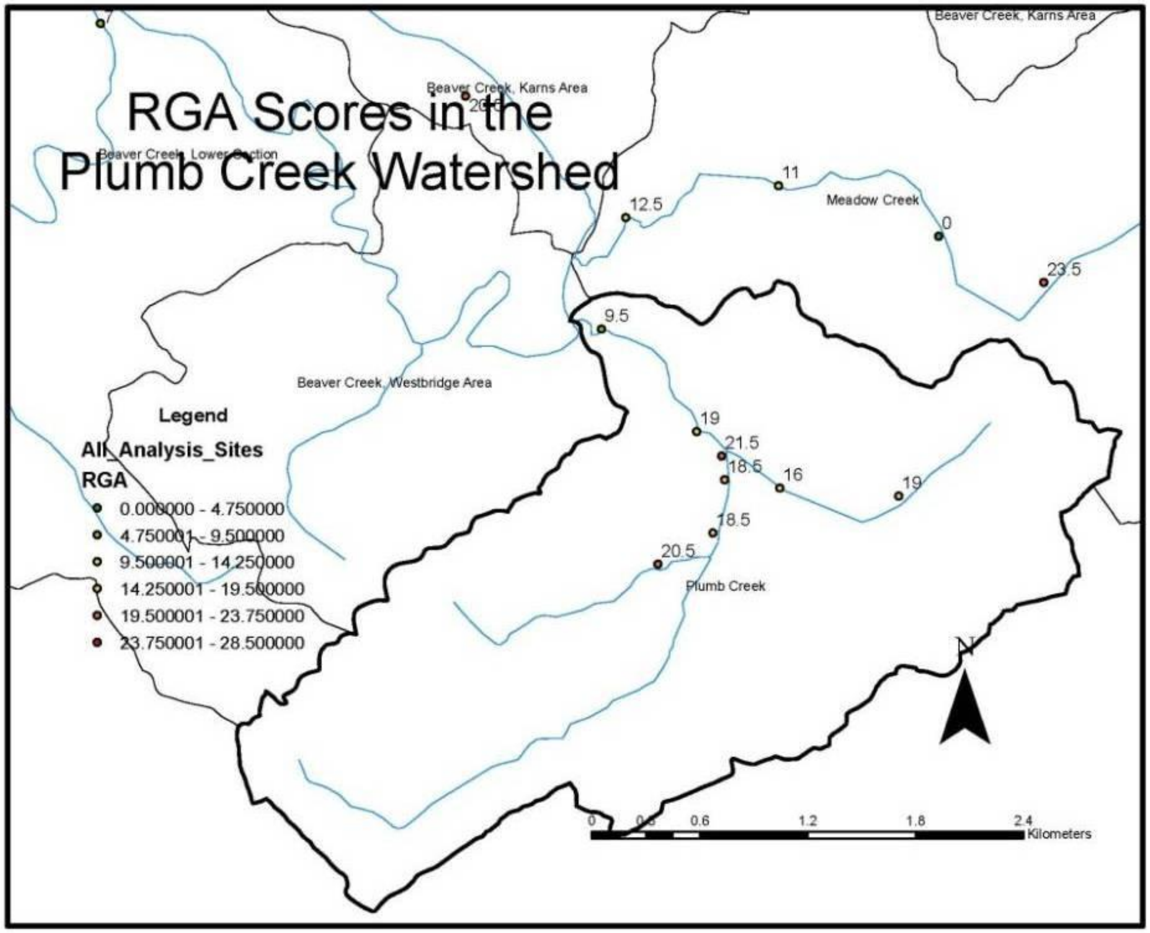


Figure 5 - RGA Scores in the Plumb Creek Watershed

Table 1 - Measured Variables in the Plub Creek Watershed

Stream	FID	D50	% Catchment Developed	% Local Developed	% Catchment Forrested	Bed Material	Incision	Left Instability
Plumb	18	10	62.10%	62.10%	31.80%	2	3	0
Plumb	19	13	64.57%	61.96%	21.48%	2	2	1
Plumb	20	13	63.40%	45.46%	22.92%	1	3	0
Plumb	21	8	66.61%	67.72%	20.66%	0	3	2
Plumb	22	8	63.34%	63.34%	22.16%	3	4	1
Plumb	a					4	1	0.5
Plumb	b					2	3	2
Plumb	c					3	3	1.5

Table 2 - Measured Variables in the Plub Creek Watershed

Stream	Site ID	Right Instability	Instability	Left Vegetation	Right Vegetation	Vegetation	Bank Accretion	SCE	RGA Score	Slope
Plumb	18	2	2	1	2	3	3.5	4	20.5	2.07
Plumb	19	0.5	1.5	0	1	1	3.5	4	19	0.24
Plumb	20	0	0	0.5	0	0.5	2.5	1.5	9.5	0.64
Plumb	21	1.5	3.5	1	0	1	3	3	18.5	0.5
Plumb	22	1	2	2	2	4	1	2	19	0.56
Plumb	a	1	1.5	1	1.5	2.5	0	3	16	
Plumb	b	2	4	0.5	0	0.5	0	4	18.5	
Plumb	c	1.5	3	0	0	0	3.5	4	21.5	

6.2 Meadow Creek

Four sites in the Meadow Creek watershed were fully assessed, all of which were located along the single main stem of the creek. From downstream to upstream, they were sites 5, 8, 7 and 6. In addition, one site was assessed with the RGA, its slope and pebble count measurements were taken, but it was not included in the calculations of catchment land cover. These sites are marked with letter identifiers, complete sites are marked with numbered identifiers. Of the study area in this watershed 47.78% is developed, 14.09% is covered by impervious surfaces and 30.72% remains forested. It is included in the Medium Development group of watersheds. Figure 6 shows the spatial relationship of the Stage of Chanel Evolution in the watershed, and Figure 7 shows the RGA scores at each site.

Rapid geomorphic assessment scores and sub-watershed characteristics are presented in Tables 3 and 4. Two sites (#6 and #7), which were located further upstream, received scores greater than 20, while the two downstream sites (#5 and #8) were significantly more stable.

6.3 Grassy Creek

Eight sites in the Grassy Creek watershed were evaluated fully. Grassy Creek splits into two main branches over the course of its flow. Two sites were located below the confluence (Site 13 and Site 12), three sites were located along the southern branch (Site 14, Site 10 and Site 9), and three sites were located along the northern branch (Site 16, Site 17 and Site 15). In addition, one site was assessed with the RGA, but no slope or pebble count measurements were taken. This site is marked with letter identifiers, complete sites are marked with numbered identifiers. In the study area (upstream of the furthest downstream study site), the watershed is 46.30% developed, with 14.75% being covered by impervious surfaces and 35.15% remaining

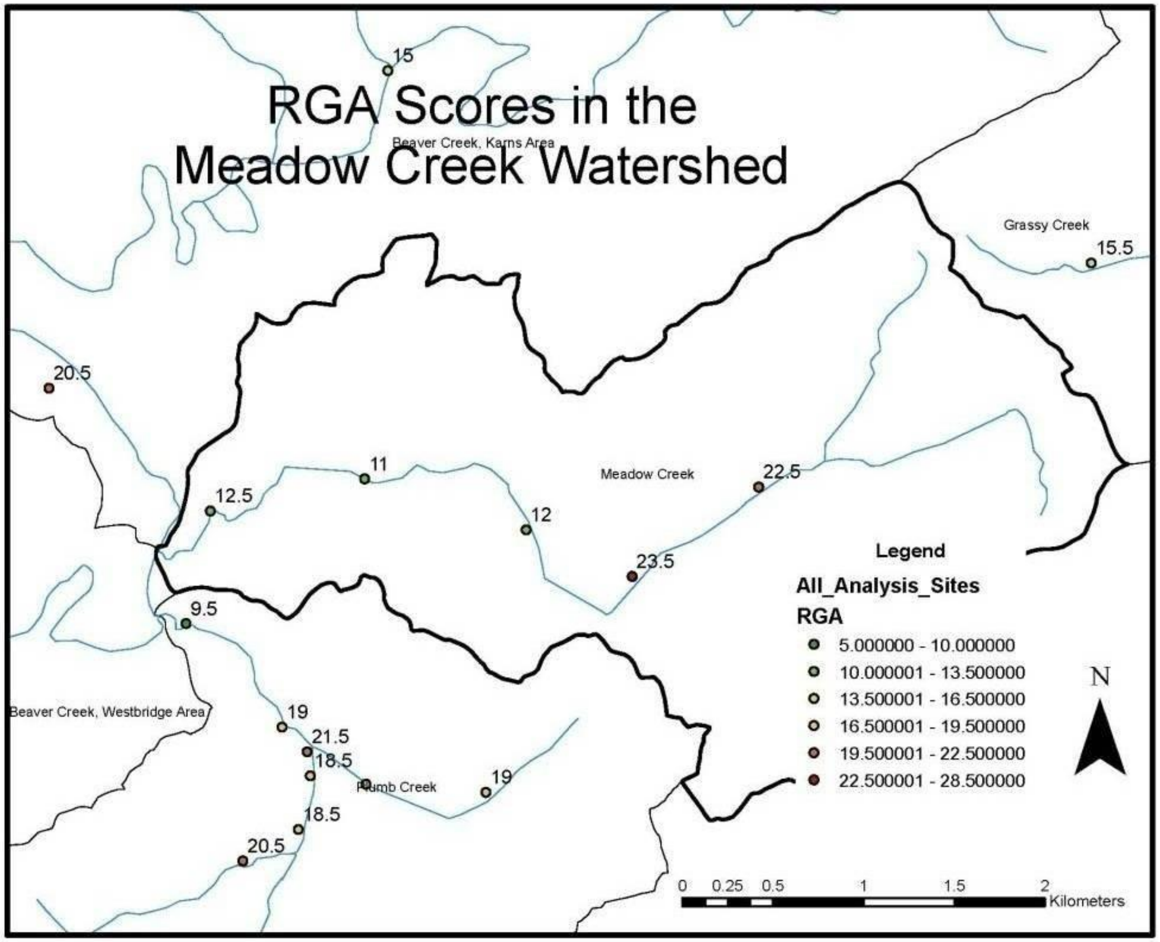


Figure 6 - RGA Scores in the Meadow Creek Watershed

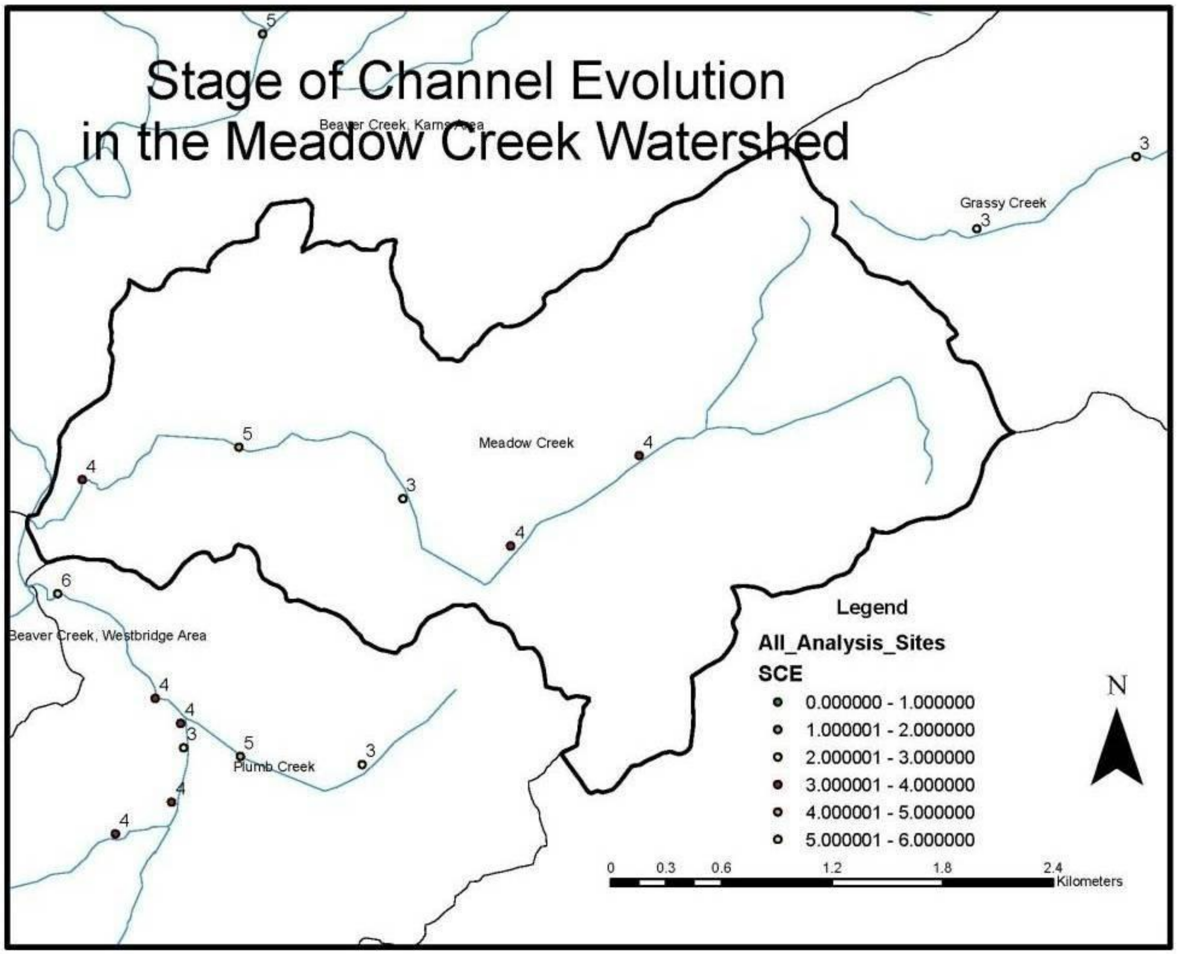


Figure 7 - Stages of Channel Evolution in the Meadow Creek Watershed

Table 3 - Measured Variables in the Meadow Creek Watershed

Stream	Site ID	D50	% Catchment Developed	% Catchment Forrested	% Impervious	Bed Material	Incision	Left Instability
Meadow	5	11	47.78%	30.72%	14.09%	2.5	2	1
Meadow	6	9	33.32%	40.56%	8.49%	3	3	1.5
Meadow	7		37.69%	35.57%	9.52%	4	2	1.5
Meadow	8	18	43.59%	34.72%	11.40%	1	3	0.5
Meadow	a	8				2	1	2

Table 4 - Measured Variables in the Meadow Creek Watershed

Stream	Site ID	Right Instability	Instability	Left Veg	Right Veg	Vegetation	Bank Accretion	SCE	RGA Score	Slope
Meadow	5	0	1	0	0	0	2	4	12.5	0.042
Meadow	6	1.5	3	1	0.5	1.5	3	4	22.5	0.132
Meadow	7	2	3.5	0.5	0.5	1	4	4	23.5	0.051
Meadow	8	0	0.5	0.5	0	0.5	1	3	11	0.036
Meadow	a	0	1	0.5	0.5	1	3	2	12	0.078

forested. These characteristics put the Grassy Creek watershed in the Medium Development category. Figure 8 shows the spatial relationship of the Stage of Chanel Evolution in the watershed, and Figure 9 shows the RGA scores at each site.

Rapid geomorphic assessment scores and sub-watershed characteristics are presented in Tables 5 and 6. RGA scores, with the exception of Site 9 and Site 16, are all in the unstable range, above 20.

6.4 Knob Fork / Haw Branch

Eight sites were fully assessed in the Knob Fork watershed. Five sites were on Knob Fork itself, and three were located on its major tributary, Haw Branch. Progressing upstream, they were Site 4, Site 3, Site 0, Site 1, and Site 2 on Knob Fork itself, and Site 58, Site 60 and Site 59 on Haw Branch. In addition, eleven sites were assessed with the RGA, but no slope or pebble count measurements were taken. These sites are marked with letter identifiers, complete sites are marked with numbered identifiers. The Knob Fork watershed study area was found to be 59.62% developed, have 18.68% of its area covered by impervious surfaces, and remain 36.23% forested.   These results place the Knob Fork watershed in the High Development category. Figure 10 shows the spatial relationship of the Stage of Chanel Evolution in the watershed, and Figure 11 shows the RGA scores at each site.

Rapid geomorphic assessment scores and sub-watershed characteristics are presented in Tables 7 and 8. Only three sites in the Knob Fork watershed had rapid geomorphic assessment scores in the unstable range, although none of them were notably low.

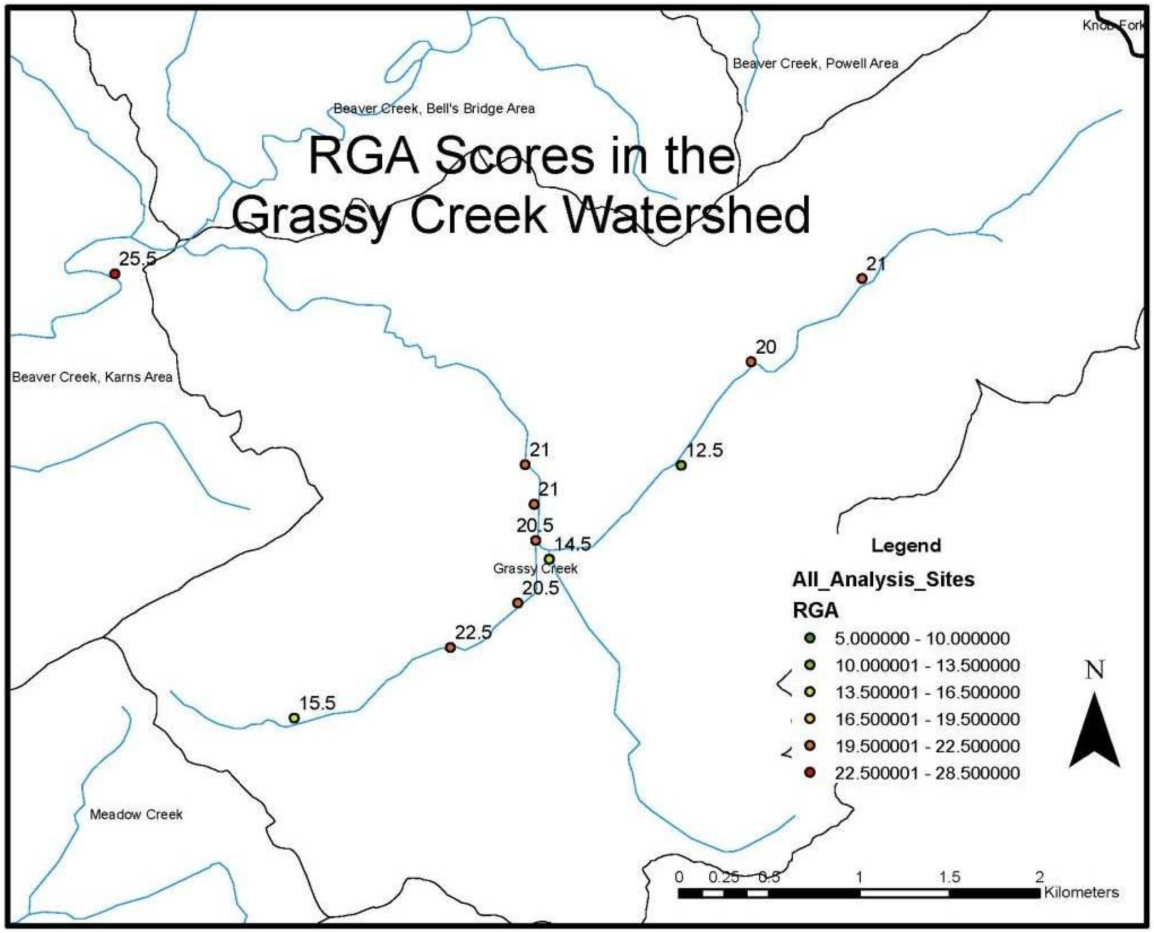


Figure 8 - RGA Scores in the Grassy Creek Watershed

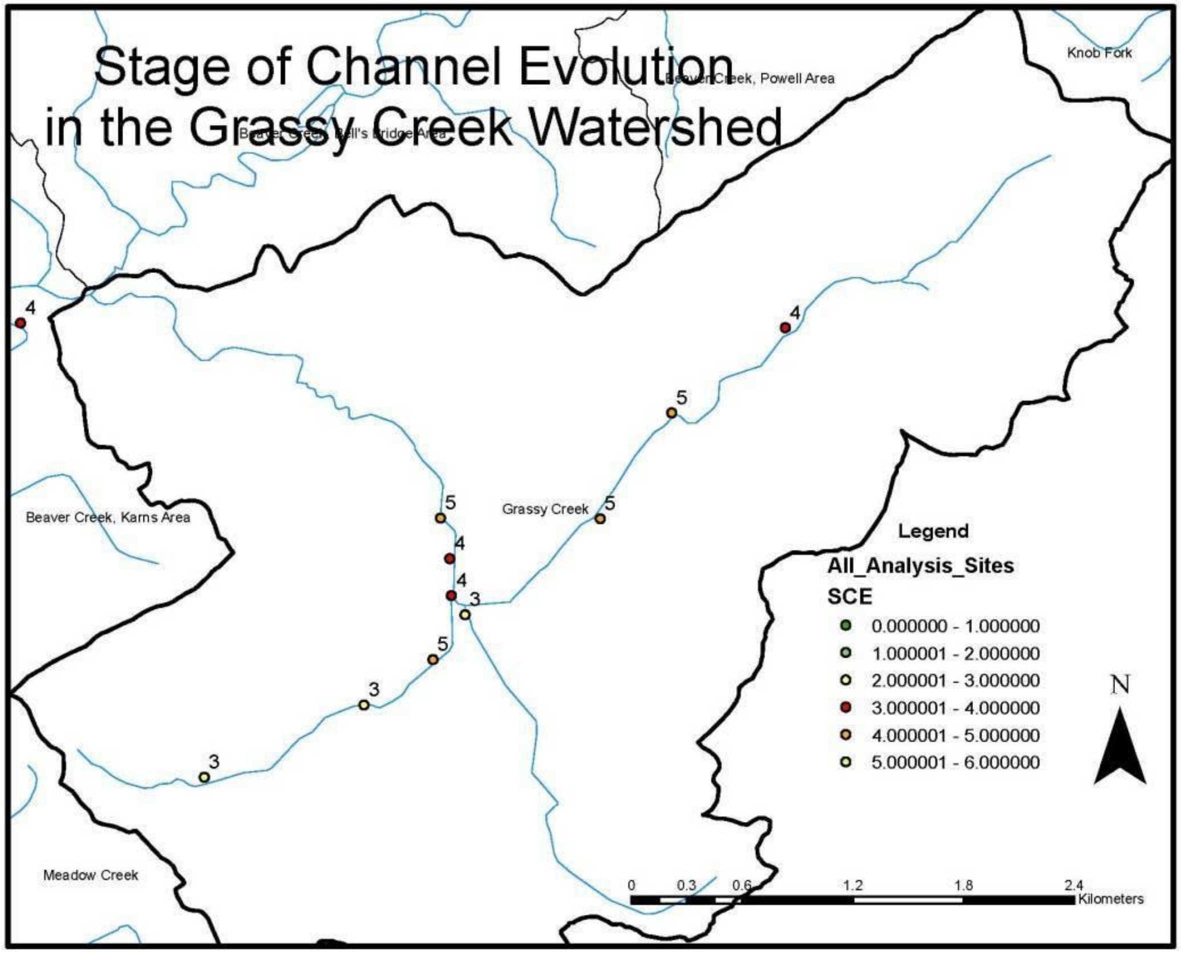


Figure 9 - Stages of Channel Evolution in the Grassy Creek Watershe

Table 5 - Measured Variables in the Grassy Creek Watershed

Stream	Site ID	D50	% Catchment Developed	% Catchment Forrested	% Impervious	Bed Material	Incision	Left Instability	Right Instability
Grassy	9	11	53.47%	35.69%	13.83%	2	3	1	1
Grassy	10	9	45.25%	38.07%	12.70%	2.5	3	1	1.5
Grassy	12	10	46.17%	35.22%	14.83%	2	2	2	2
Grassy	13	0.033	46.30%	35.15%	14.75%	4	1	1.5	2
Grassy	14	7	41.27%	36.40%	11.36%	3	2	1.5	1.5
Grassy	15	16	56.32%	26.92%	25.18%	2	3	1.5	1.5
Grassy	16	12	53.18%	31.46%	19.58%	2	2	0.5	0
Grassy	17	13	55.23%	27.63%	22.51%	2	2	1	1.5
Grassy	a					3	1	2	2

Table 6 - Measured Variables in the Grassy Creek Watershed

Stream	Site ID	Instability	Left Vegetation	Right Vegetation	Vegetation	Bank Accretion	SCE Score	RGA Score	Slope
Grassy	9	2	0.5	1.5	2	1.5	2	15.5	0.036
Grassy	10	2.5	1.5	2	3.5	4	2	22.5	0.079
Grassy	12	4	0.5	0.5	1	3	4	21	0.002
Grassy	13	3.5	1	0.5	1.5	3	3	21	0.13
Grassy	14	3	1.5	1	2.5	2	3	20.5	0.04
Grassy	15	3	0.5	0.5	1	3	4	21	0.101
Grassy	16	0.5	0.5	0.5	1	1	3	12.5	0.039
Grassy	17	2.5	2	0	2	2.5	3	20	0.147
Grassy	a	4	0	0.5	0.5	3	4	20.5	0

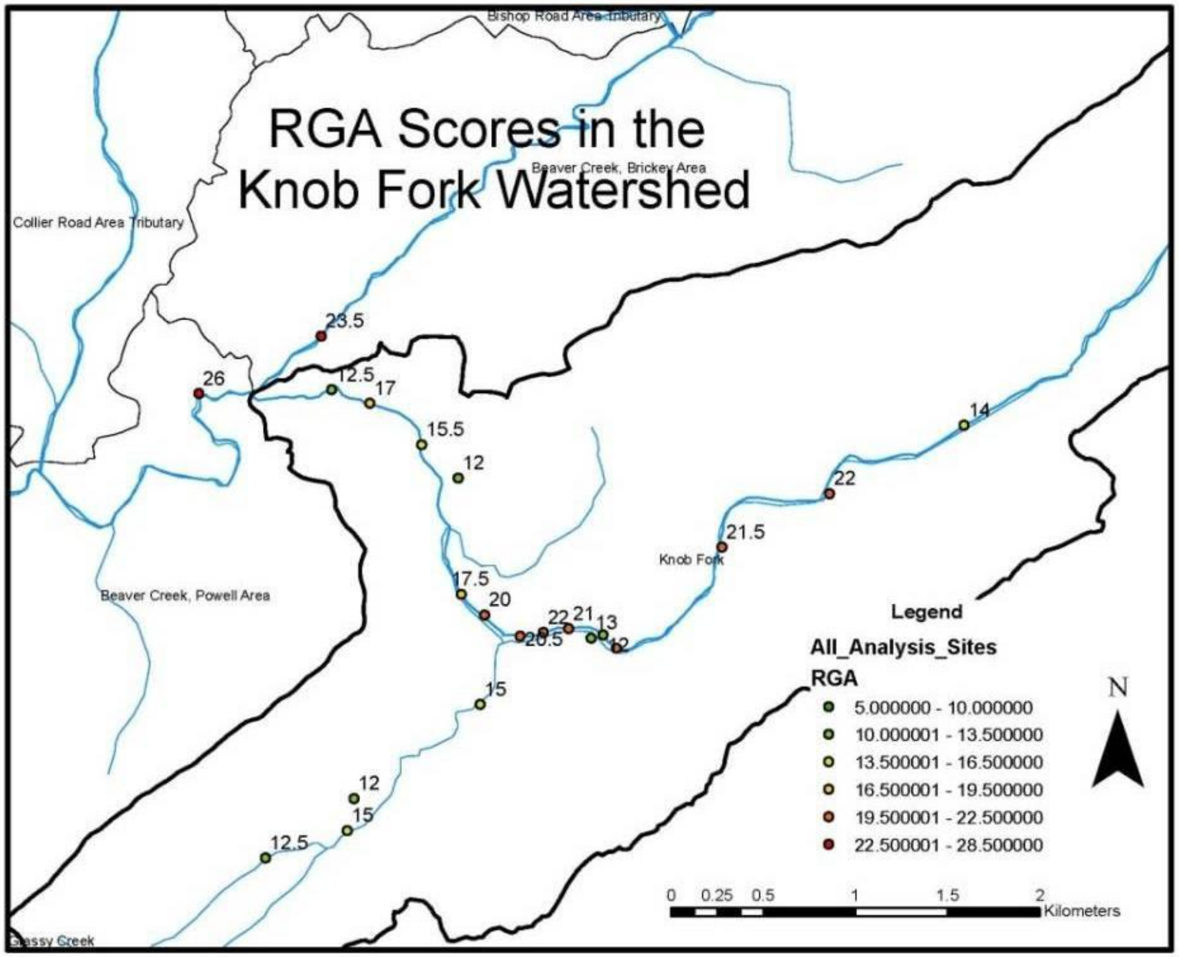


Figure 10 - RGA Scores in the Knob Fork Watershed

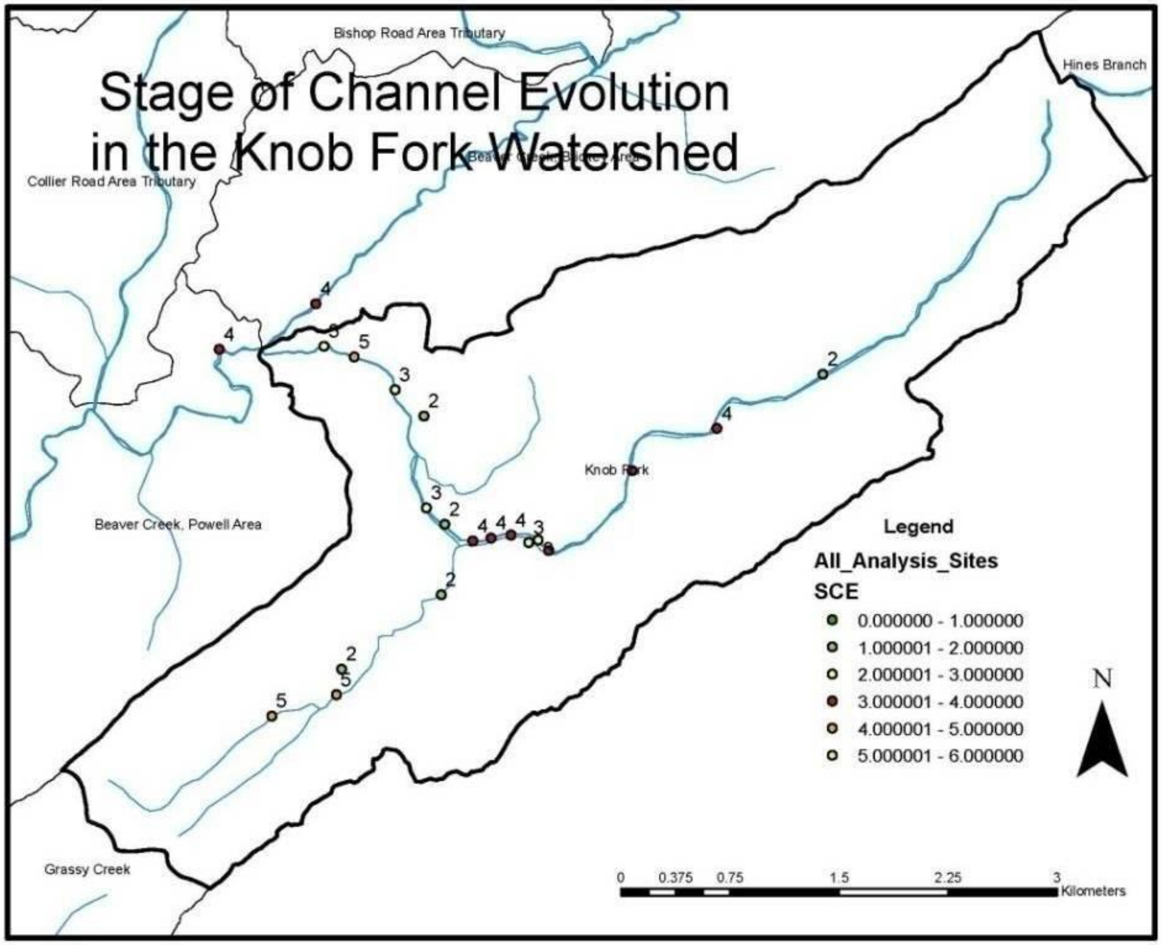


Figure 11 - Stages of Channel Evolution in the Knob Fork Watershed

Table 7 - Measured Variables in the Knob Fork Watershed

Stream	Site ID	D50	% Catch Developed	% Catchment Forrested	% Impervious	Bed Material	Incision	Left Instability
Knob	0	11	58.72%	38.90%	16.30%	2	2	1.5
Knob	1	9	58.55%	40.21%	17.53%	2	3	1
Knob	2	16	55.99%	42.91%	14.92%	3	2	0
Knob	3	14	58.72%	38.90%	16.30%	2	2	1.5
Knob	4	11	59.62%	36.23%	18.68%	2	2	1
Haw	58	15	61.42%	31.04%	23.11%	2	1	0
Haw	59		60.06%	22.51%	25.95%	0	2	0.5
Haw	60		60.45%	30.95%	21.27%	2	3	1
Knob	a					2	3	2
Knob	b					2	2	1.5
Knob	c					3	1	2
Knob	d					2	2	2
Knob	e					1	2	0
Knob	f					3	1	0
Knob	g					2	4	0
Knob	h					3	0	0
Knob	i					1	2	2
Knob	j					0	2	0.5
Knob	k					3	1	0

Table 8 - Measured Variables in the Knob Fork Watershed

Stream	Site ID	Right Instability	Instability	Left Vegetation	Right Vegetation	Vegetation	Bank Accretion	SCE Score	RGA Score	Slope
Knob	0	1.5	3	2	2	4	1.5	4	21.5	0.035
Knob	1	1	2	2	2	4	4	4	22	0.1
Knob	2	0	0	0	0	0	4	2	14	0.053
Knob	3	1.5	3	1	0.5	1.5	3.5	4	21	0.025
Knob	4	1	2	0	0	0	3	3	17	0
Haw	58	0	0	2	2	4	4	1	15	0.005
Haw	59	0.5	1	1.5	1	2.5	1	3	12.5	0.038
Haw	60	0	1	0	0	0	2	3	15	0.088
Knob	a	1.5	3.5	1	0.5	1.5	3	4	22	
Knob	b	2	3.5	0.5	1	1.5	2.5	4	20.5	
Knob	c	2	4	2	2	4	4	1	20	
Knob	d	2	4	1	0.5	1.5	3	2	17.5	
Knob	e	0	0	1	1	2	3	1	12	
Knob	f	0	0	1.5	1	2.5	4	2	15.5	
Knob	g	0	0	0	0	0	2	1	12	
Knob	h	0	0	0.5	0	0.5	4	2	12.5	
Knob	i	0	2	2	1.5	3.5	2.5	4	20	
Knob	j	0.5	1	1	0.5	1.5	2.5	2	12	
Knob	k	0	0	0	0	0	4	2	13	

Five sites were fully assessed along Hines Branch. Progressing upstream, they were Site 24, Site 25, Site 27, Site 26 and Site 23. In addition, four sites were assessed with the RGA, but no slope or pebble count measurements were taken. These sites are marked with letter identifiers, complete sites are marked with numbered identifiers. In the Hines Branch study area, 66.25% of the land is developed, 21.13% is covered by impervious surfaces and 29.59% is forested. Thus, the Hines Branch watershed is grouped in the High Development category. Figure 12 shows the spatial relationship of the Stage of Chanel Evolution in the watershed, and Figure 13 shows the RGA scores at each site.

Rapid geomorphic assessment scores and sub-watershed characteristics are presented in Tables 9 and 10. Only one site received an unstable score, but it was unusually high. Site 24 was the furthest downstream. It received the worst possible score in every category except incision and bed material; the 2.5 it was assigned in the bed material category was because of a thin layer of sand and gravel covering a deeper bed of silt/clay. It was a relatively low slope reach, as it was in the valley bottom, near the confluence with Beaver Creek. The site was unique in that the level of development in its entire catchment was 66.25%, while the level of development in the catchment between Site 24 and the next upstream assessment site was 43.9%. This fits with the theory that headwater development will reduce sediment delivery and increase peak flows, causing erosion and instability.

6.6 Headwaters Streams

The headwaters region of the Beaver Creek watershed is generally considered to be the area around and upstream of the point at which Beaver Creek flows under State Route 33 (Maynardville Pike). Several small streams are located here, including North Fork, Mill Branch,

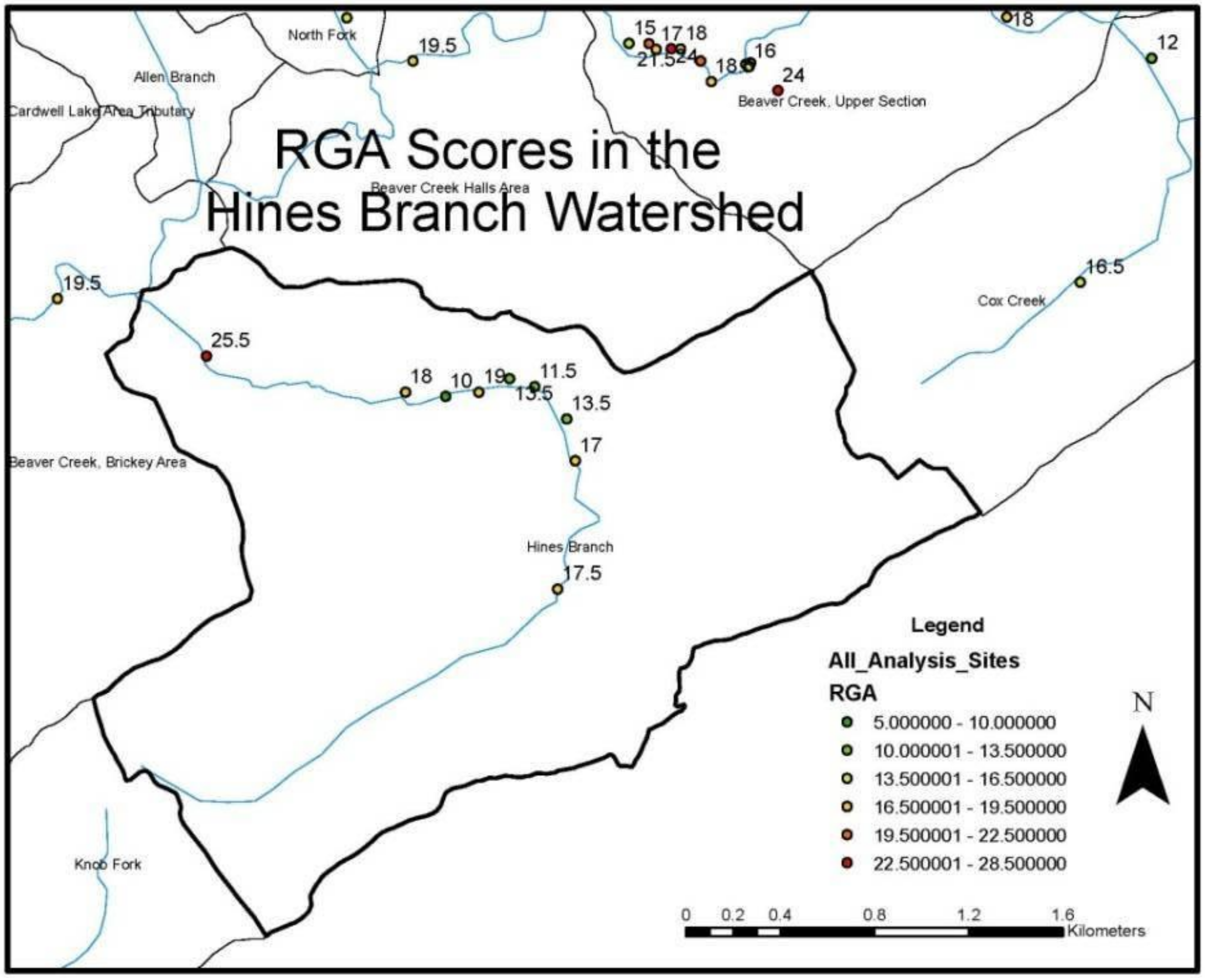


Figure 12 - RGA Scores in the Hines Branch Watershed

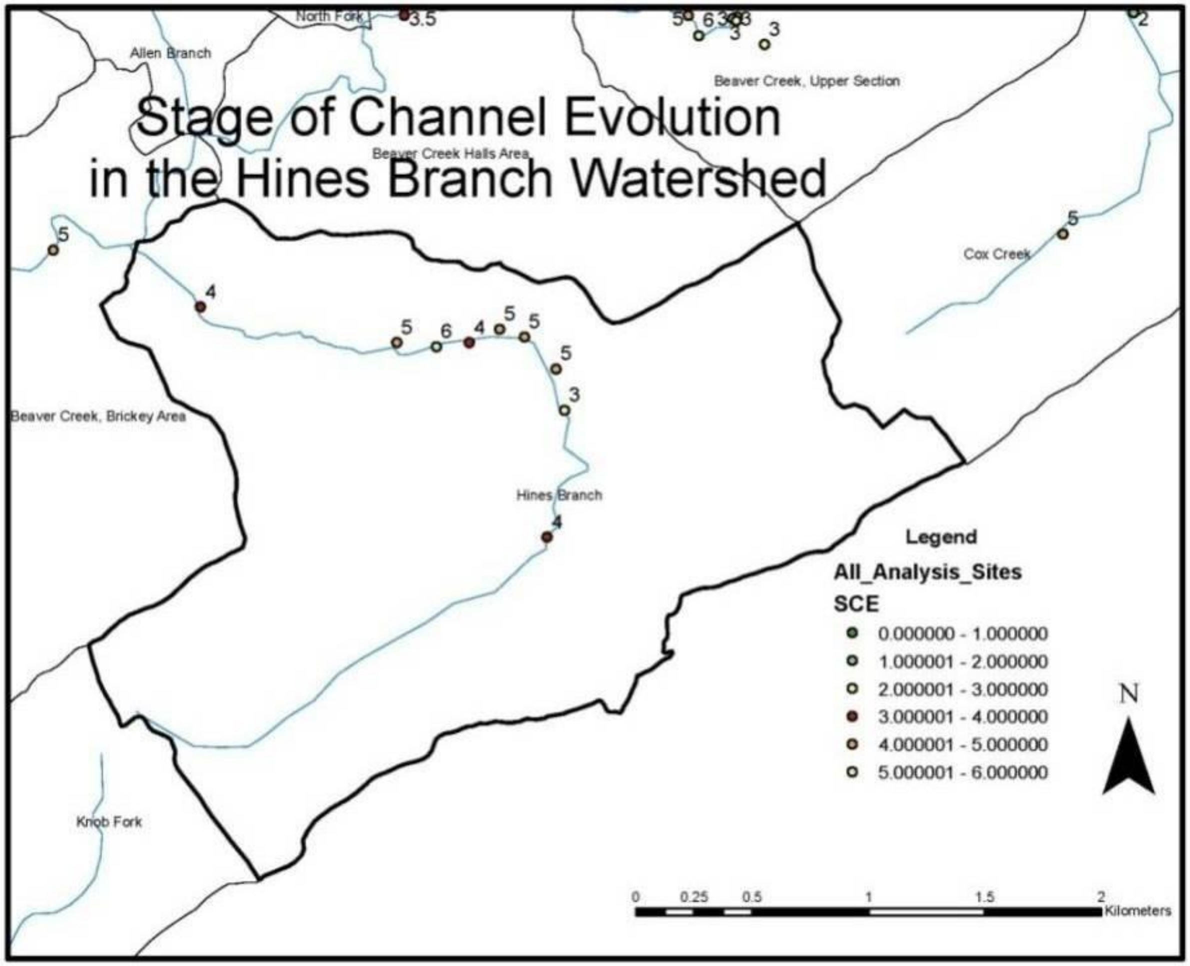


Figure 13- Stages of Channel Evolution in the Hines Branch Watershed

Table 9 - Measured Variables in the Hines Branch Watershed

Stream	Site ID	D50	% Catchment Developed	% Catchment Forrested	% Impervious	Bed Material	Incision	Left Instability
Hines	23	8	72.74%	25.39%	21.31%	1	3	2
Hines	24	7	66.25%	29.59%	21.13%	2.5	2	2
Hines	25	13	71.32%	26.59%	22.47%	2	3	2
Hines	26	9	72.28%	25.71%	21.55%	3	2	1
Hines	27	9	71.70%	26.32%	22.17%	2	2	0
Hines	a					3	2	1
Hines	b					3	0	0.5
Hines	c					1	3	0
Hines	d					2	2	0

Table 10 - Measured Variables in the Hines Branch Watershed

Stream	Site ID	Right Instability	Instability	Left Vegetation	Right Vegetation	Vegetation	Bank Accretion	SCE Score	RGA Score
Hines	23	1	3	0	0	0	2.5	4	17.5
Hines	24	2	4	2	2	4	4	4	25.5
Hines	25	1	3	0.5	0	0.5	3.5	4	19
Hines	26	0	1	0.5	2	2.5	0	3	13.5
Hines	27	0.5	0.5	1.5	1.5	3	1	3	13.5
Hines	a	1	2	0.5	0.5	1	2	3	18
Hines	b	0	0.5	0	0.5	0.5	2.5	1.5	10
Hines	c	1	1	1.5	1	2.5	1	3	11.5
Hines	d	0	0	2	2	4	4	2	17

Willow Fork, Lammie Branch, Kerns Branch, Cox Creek and a stretch of Beaver Creek. Fifteen sites were evaluated in this area, on several streams. Site 56 was on North Fork, Site 30 was on Willow Fork, Site 57 was on Mill Branch, Site 29 and Site 28 were on Lammie Branch, Site 61 was on Kerns Branch, Site 54 was on the southern branch of Cox Creek, Site 52 and Site 53 were on the northern branch of Cox Creek and on Beaver Creek itself were located Site 51, Site 34, Site 45, Site 37, Site 44, Site 38 and site 36. In the Headwaters study area, 22.04% of the land was found to be developed, 7.28% was covered by impervious surfaces and 31.84% of the land is forested. These watersheds were all grouped in the Low Development category. Figure 14 shows the spatial relationship of the Stage of Chanel Evolution in the watershed, and Figure 15 shows the RGA scores at each site. Additionally, Figure 16 and Figure 17 show a detailed view of the assessment sites near Halls.

Rapid geomorphic assessment scores and sub-watershed characteristics are presented in Tables 11 and 12. The headwaters area includes both the most stable site assessed (Site 28) and the most unstable (Site 29). They are both located on Lammie Branch, with Site 28 a little over a kilometer upstream of Site 29.

Figure 18 shows a site on Lammie Branch which received an RGA score of 5. It was located in a relatively undisturbed area, in a small valley in which the only apparent development was a single two lane road. Figure shows a site which received an RGA score of 28.5. It was also located on Lammie, about 1 kilometer downstream of the site shown in Figure 19, in a pasture used for cattle grazing. Just upstream of the site, the cows had access to the stream and had caused significant instability on the banks. This, coupled with the mostly silt bed material, lack of woody vegetation and lack of

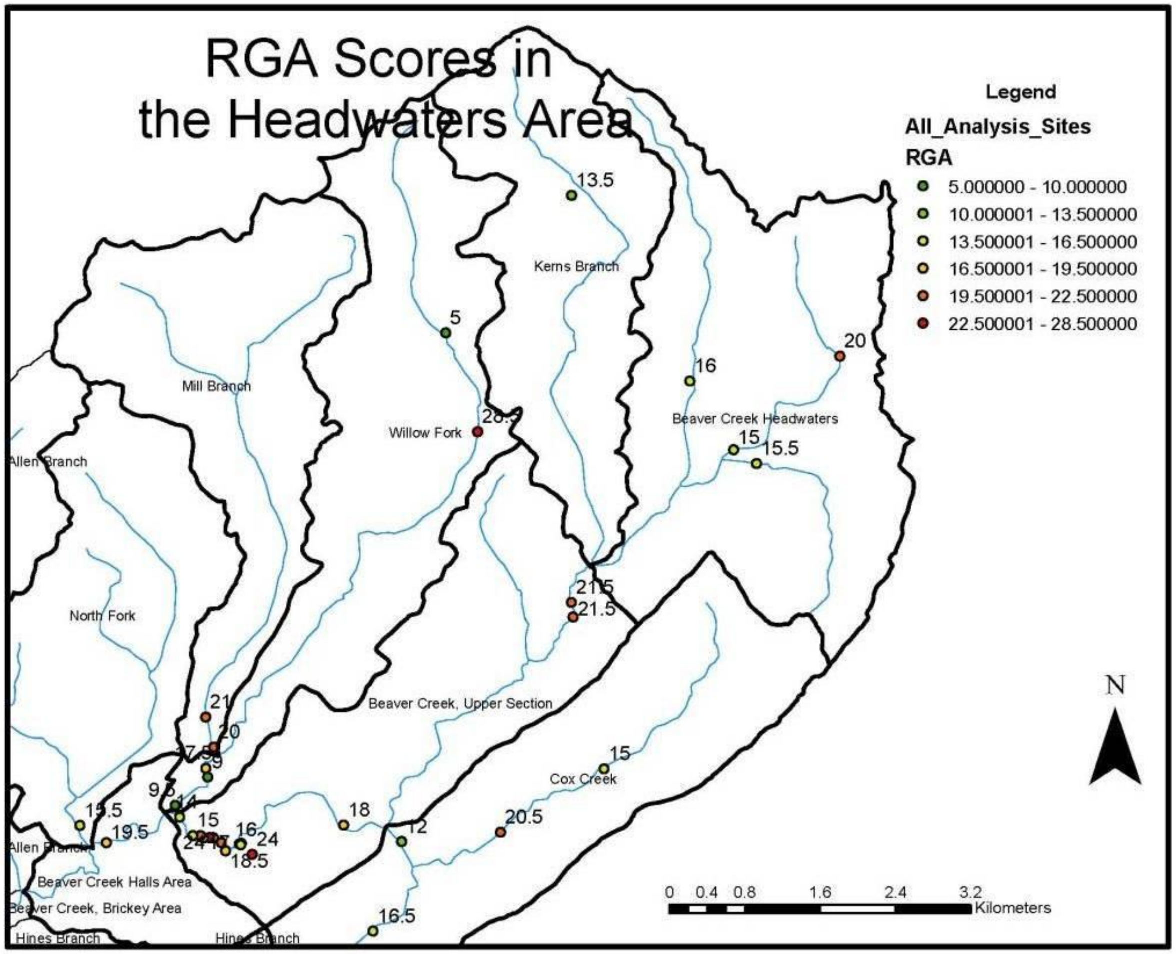


Figure 14 - RGA Scores in the Headwaters Watersheds

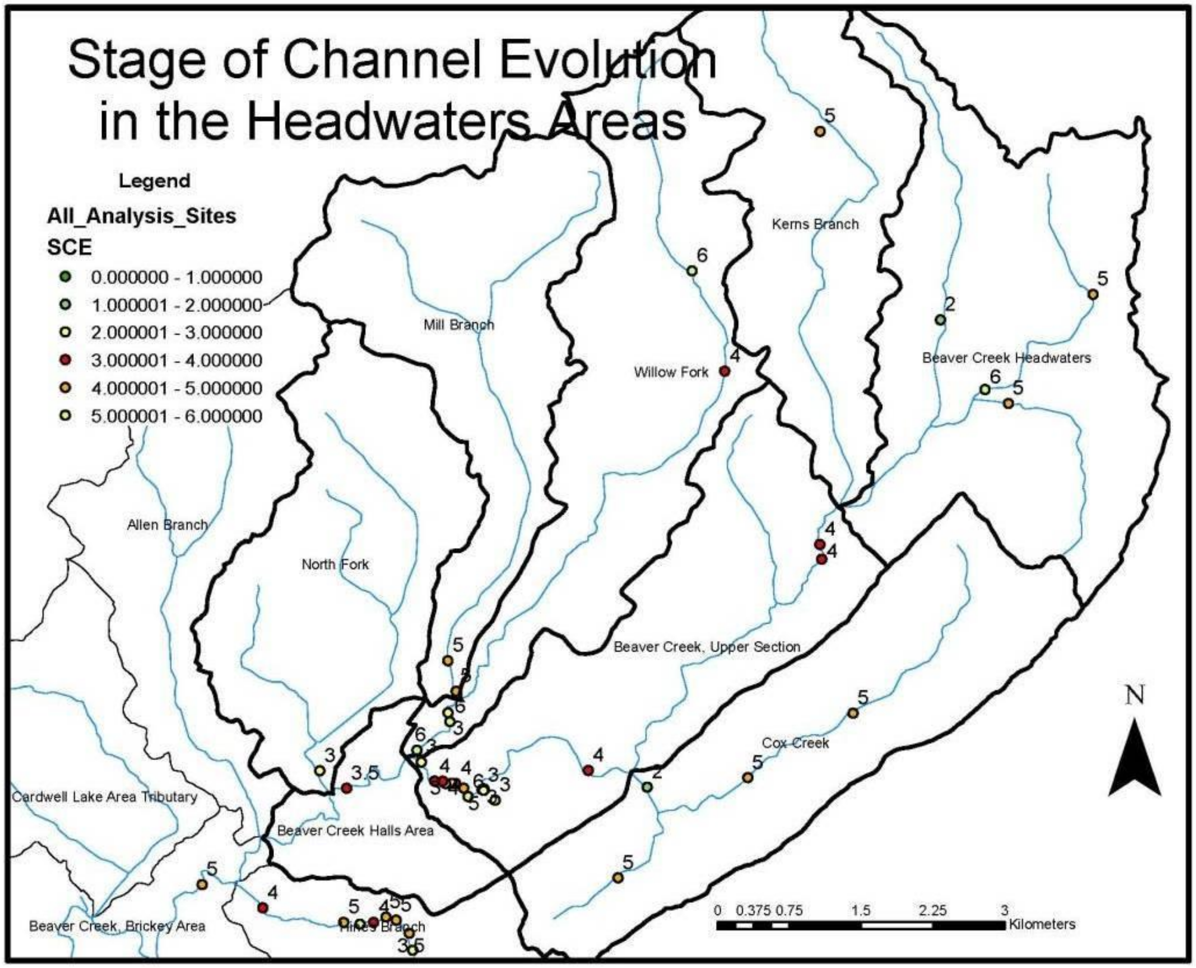


Figure 15 - Stages of Channel Evolution in the Headwaters Watersheds

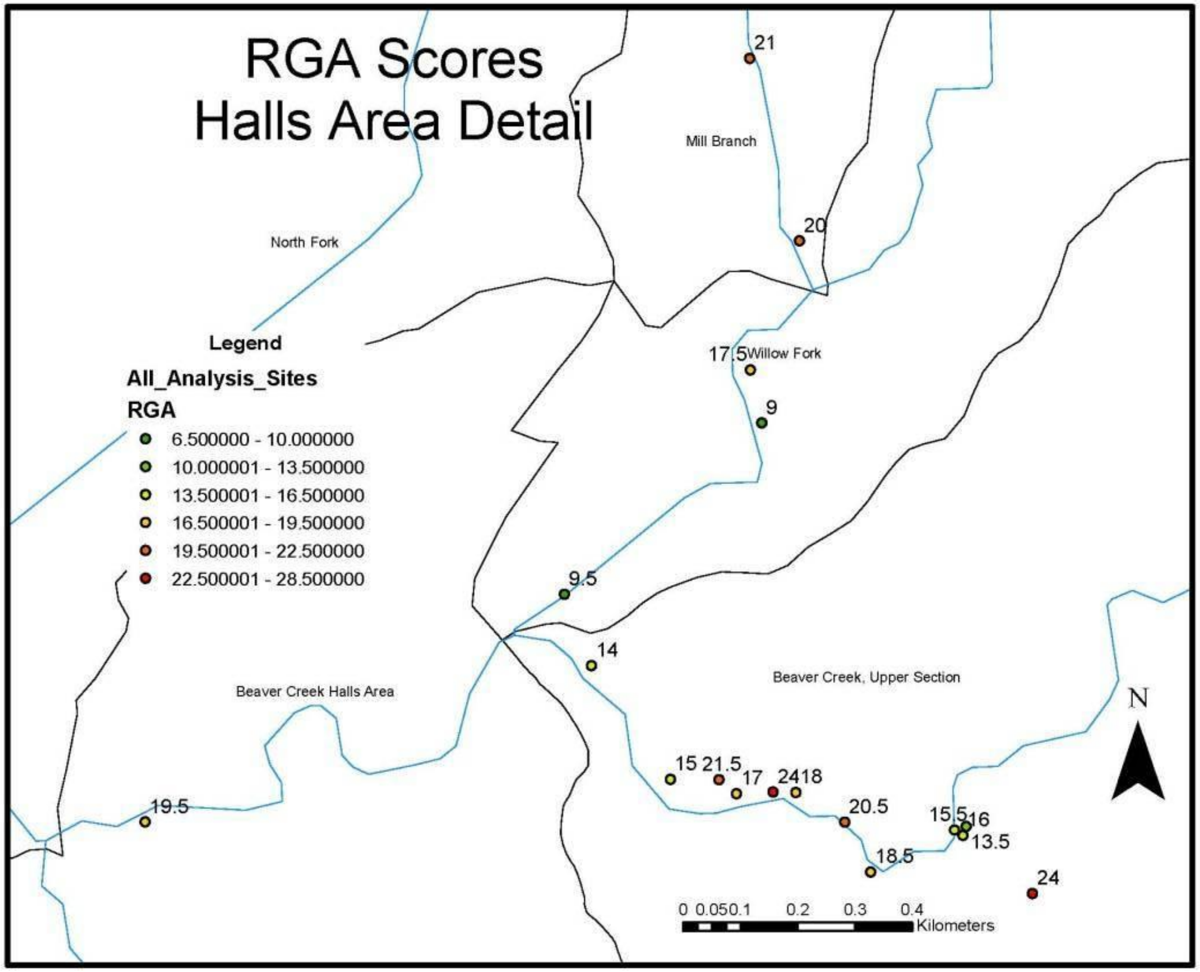


Figure 16 - Detail of RGA Scores in the Halls Area

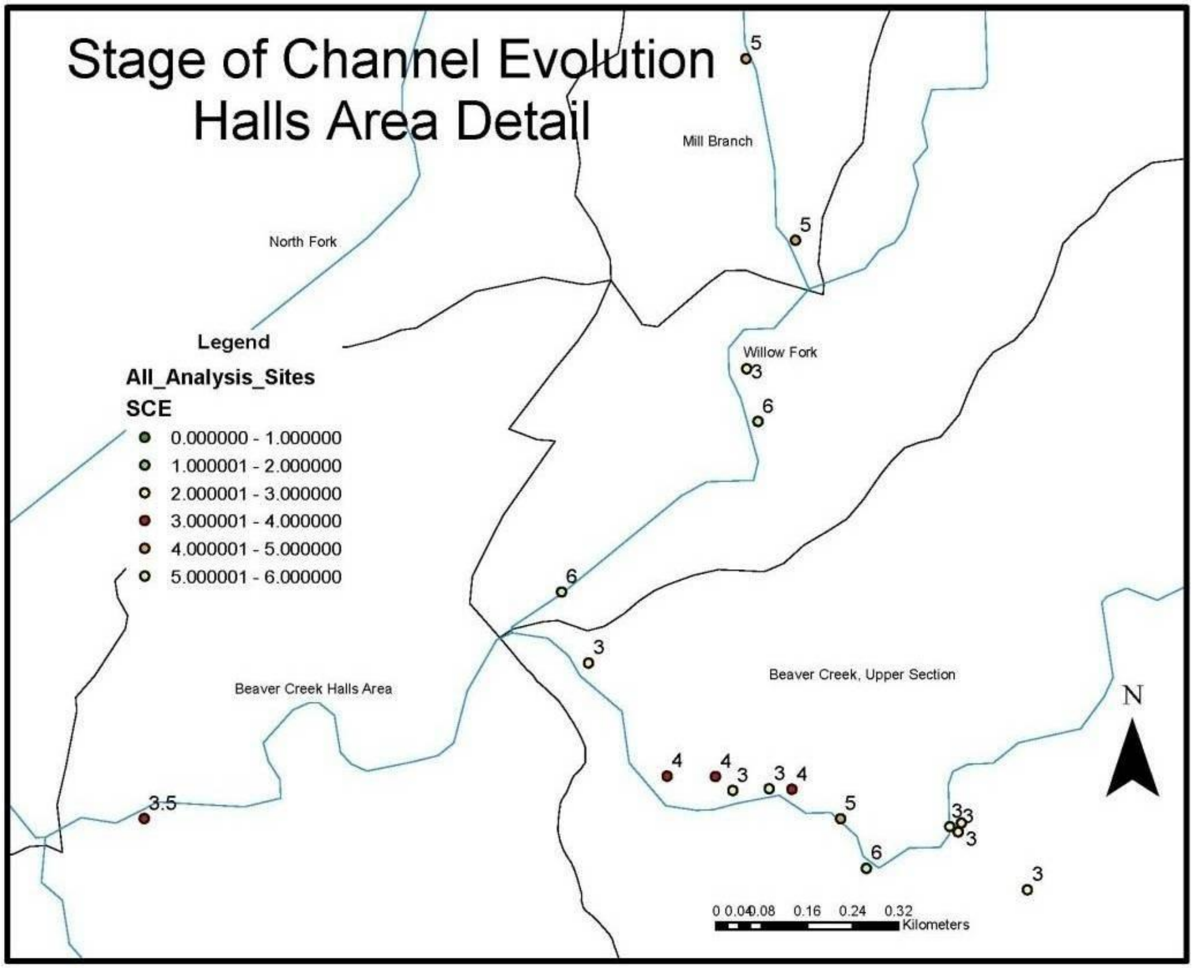


Figure 17 - Detail of the Stages of Channel Evolution in the Halls Area

Table 11- Measured Variables in the Headwaters Watersheds

Stream	Site ID	D50	% Catchment Developed	% Local Developed	% Catchment Forrested	% Impervious	Bed Material	Incision	Left Instability
Lammie	28	26	12.90%	8.59%	19.49%	4.68%	1	1	0
Lammie	29		10.92%	7.14%	23.19%	4.20%	3	3	2
Willow	30		17.23%	18.64%	32.89%	5.82%	4	1	0
Cox	52	0.033	14.63%	21.34%	46.00%	4.92%	4	2	1.5
Cox	53	8	11.62%	11.62%	44.46%	4.22%	4	3	0
Cox	54	5	60.44%	60.44%	34.57%	15.54%	3	2	1
North Fork	56	0.033	42.18%	42.18%	14.14%	12.29%	4	3	0
Mill	57	9	18.24%	18.24%	37.26%	6.07%	2	2	2
Haw	58	15	61.42%	64.33%	31.04%	23.11%	2	1	0
Haw	59		60.06%	69.39%	22.51%	25.95%	0	2	0.5
Haw	60		60.45%	60.73%	30.95%	21.27%	2	3	1
Kerns	61	18	7.60%	7.60%	54.61%	3.46%	1	1	0
Beaver	34	4	22.46%	53.45%	31.84%	7.18%	3	2	0
Beaver	36	0.033	14.30%	14.30%	12.90%	4.98%	4	4	1.5
Beaver	37	7	15.24%	14.65%	26.81%	5.73%	3	2	1
Beaver	38	10	13.39%	13.30%	29.17%	5.49%	0	2	0
Beaver	44	27	22.22%	28.48%	14.98%	7.50%	1	4	1
Beaver	45	3	20.00%	25.03%	32.34%	6.62%	4	2	0.5
Beaver	51	0.033	22.04%	72.20%	31.84%	7.28%	4	1	2

Table 12 - Measured Variables in the Headwaters Watersheds

Stream	Site ID	Right Instability	Instability	Left Vegetation	Right Vegetation	Vegetation	Bank Accretion	SCE Score	RGA Score	Slope (%)
Lammie	28	0	0	0.5	0.5	1	0	0	5	1.76
Lammie	29	2	4	1.5	2	3.5	3	4	28.5	0.38
Willow	30	0	0	0.5	1.5	2	0	1.5	9.5	0.72
Cox	52	1.5	3	1	0.5	1.5	2	3	20.5	1.28
Cox	53	0.5	0.5	1	0.5	1.5	1	3	15	0.17
Cox	54	0.5	1.5	0.5	0	0.5	3.5	3	16.5	0.25
North Fork	56	0	0	0.5	0.5	1	3.5	2	15.5	0.15
Mill	57	0.5	2.5	0.5	1.5	2	3.5	3	20	0.46
Haw	58	0	0	2	2	4	4	1	15	0.05
Haw	59	0.5	1	1.5	1	2.5	1	3	12.5	0.38
Haw	60	0	1	0	0	0	2	3	15	0.88
Kerns	61	1	1	2	1.5	3.5	1	3	13.5	1.75
Beaver	34	0	0	0	0	0	4	2	14	0.01
Beaver	36	2	3.5	0.5	0	0.5	0	3	20	0.37
Beaver	37	1.5	2.5	1.5	0.5	2	3	4	21.5	0.02
Beaver	38	1	1	0.5	1	1.5	4	3	15.5	0.16
Beaver	44	1	2	0	0.5	0.5	3	1.5	15	0.56
Beaver	45	1	1.5	0	0.5	0.5	2.5	4	18	0.04
Beaver	51	1	3	1.5	0.5	1.5	2.5	3	19.5	0

Figure 18 - Lammie Branch, Site 12. Channel Stability Index: 5

Figure 19 - Lammie Branch, Site 13, Channel Stability Index: 28.5

aggrading material led to the high RGA score. Restricted access to the stream prevented an investigation of the condition of the channel between these sites, but their disparate nature reinforces the variability in watersheds that are affected by development.

6.7 Beaver Creek Main Stem

Eleven sites were evaluated on the main stem of Beaver Creek downstream of the headwaters area. These were, from downstream to upstream, Site 42, Site 41, Site 39, Site 40, site 43, Site 50, Site 47, Site 46, Site 35, Site 49 and Site 48. Site 42 was located near the point at which Beaver Creek crosses Swafford Rd. and Site 48 was located about 24 km upstream, near the Beaver Brook Country Club, in Halls Crossroads. In addition, nine sites were assessed with the RGA, but no slope or pebble count measurements were taken. These sites are marked with letter identifiers, complete sites are marked with numbered identifiers. Figure 20 shows the spatial relationship of the Stage of Chanel Evolution in the watershed, and Figure 21 shows the RGA scores at each site. Rapid geomorphic assessment scores and sub-watershed characteristics are presented in Tables 13 and 14.

6.8 The Complete Watershed

No clear spatial relationship between a study site's position along the stream reach and its stage of channel evolution was revealed in this study. Nor was there a clear correlation between the degree of watershed development and channel stability. These results are supported when the entire dataset is examined for correlations. As shown in Appendix B and Appendix C, there was no apparent relationship between in the percentage of a site's local upstream area that has undergone development (r = -

0.0054, P = 0.9681) nor the percentage of the entire upstream catchment (r = -0.0370, P = 0.7848). Nor did the water surface slope of the reach influence the RGA score (r = -0.1472, P = 0.2745). Again, it should be noted that slopes were low throughout the watershed, as shown in Figure 22. The d50 particle diameter of stream bed material, however, did show a relatively strong influence (r = -0.6039, P <0.0001).

As shown in Figure 23, all the metrics used in determining the RGA score showed significant correlation with the final score, as was expected, but these were strongest with Instability (r = 0.8553, P < 0.0001), Stage of Channel Evolution (r = 0.7124, P < 0.0001), Bed Material (r = 0.4690, P = 0.0002) and Bank Accretion (r = 0.4770, P = 0.0002). The first two showed such strong correlation because they are both indicators of channel form that are controlled by the same geomorphic processes as overall stability. The latter two metrics are both channel characteristics that reflect the amount of energy available to move sediment in the reach, and are thus better indicators of stream power. Previous studies have shown that the presence of vegetative growth on and near stream banks can be one of the dominant controls of bank stability, but this was not the case in this study, as shown in Figure 24. The percent of each stream bank showing instability, and the percent of each bank covered by woody vegetation were recorded separately. There were no significant correlations between woody vegetation on the left bank and percent instability on the left bank (r = 0.1688, P = 0.2093) nor woody vegetation on right bank and percent instability on the right bank (r = 0.2007, P = 0.1345). There was weak correlation between vegetation and instability scores for both banks combined (r = 0.2301, P = 0.0851). Another expected relationship that was not apparent in the data was an influence of slope on channel incision ($r = 0.0932$, $P = 0.4903$, see Fig 18). Based on the unit stream power relationship, it was expected that as slopes increased, more erosive energy would be present and more bed material would be removed. Since there was no evident relationship between slope, incision, bed material size or stability, as shown in Figure 25, this did not appear to be the case in this watershed. It should be noted again that since almost 85% of the observed slopes were below a 1% grade, there was little variation in the sample.

In addition to the 57 Rapid Geomorphic Assessment sites at which a slope measurement and pebble count were performed, there were 34 sites at which only the RGA was conducted. As shown in Appendix C and Appendix D, there were no significant changes to the results of the statistical analysis when the additional RGA scores were included.

When the levels of development in the nine subwatersheds in the study area were compared, it appeared that the sub-basins could be divided into three groups based on the percentage of their land area that has already undergone development. Hines Creek, Plumb Creek and Knob Fork were categorized as “high” with, respectively, 66.25%, 63.40% and 59.62% (Average: 63.09%) of their land developed. Meadow Creek and Grassy Creek were classified as “Medium” with, respectively, 47.78% and 46.30% (Average: 47.04%) of their land area developed. Willow Creek and the Beaver Creek Headwaters Area (which included sites on Beaver Creek, Cox Creek and Kerns

Branch) were categorized as “Low” with, respectively, 17.23% and 22.46% (Average: 19.85%) of their land area developed.

As shown in the individual watershed analyses, as well as Appendix G and Appendix H, even among sub-basins of similar levels of development, there are no clear patterns to channel evolution. Some interesting trends in the data did emerge when pair-wise correlation analysis was performed on the different groups of sub-basins. In the High development group, none of the RGA variables had a strong correlation with overall RGA score except instability ($r = 0.8222$, $P < 0.0001$) and stage of channel evolution ($r = 0.6835$, $P = 0.0018$). Also in the High group, instability was the only variable which strongly correlated with stage of channel evolution ($r = 0.7223$, $P = 0.0007$). In the low development group, mean particle diameter also correlated strongly with RGA score ($r = -0.7580$, $P = 0.0155$), while the stage of channel evolution correlated well with mean particle diameter ($r = -0.8292$, $P = 0.0057$) and average surface slope ($r = -0.7580$, $P = 0.0069$).

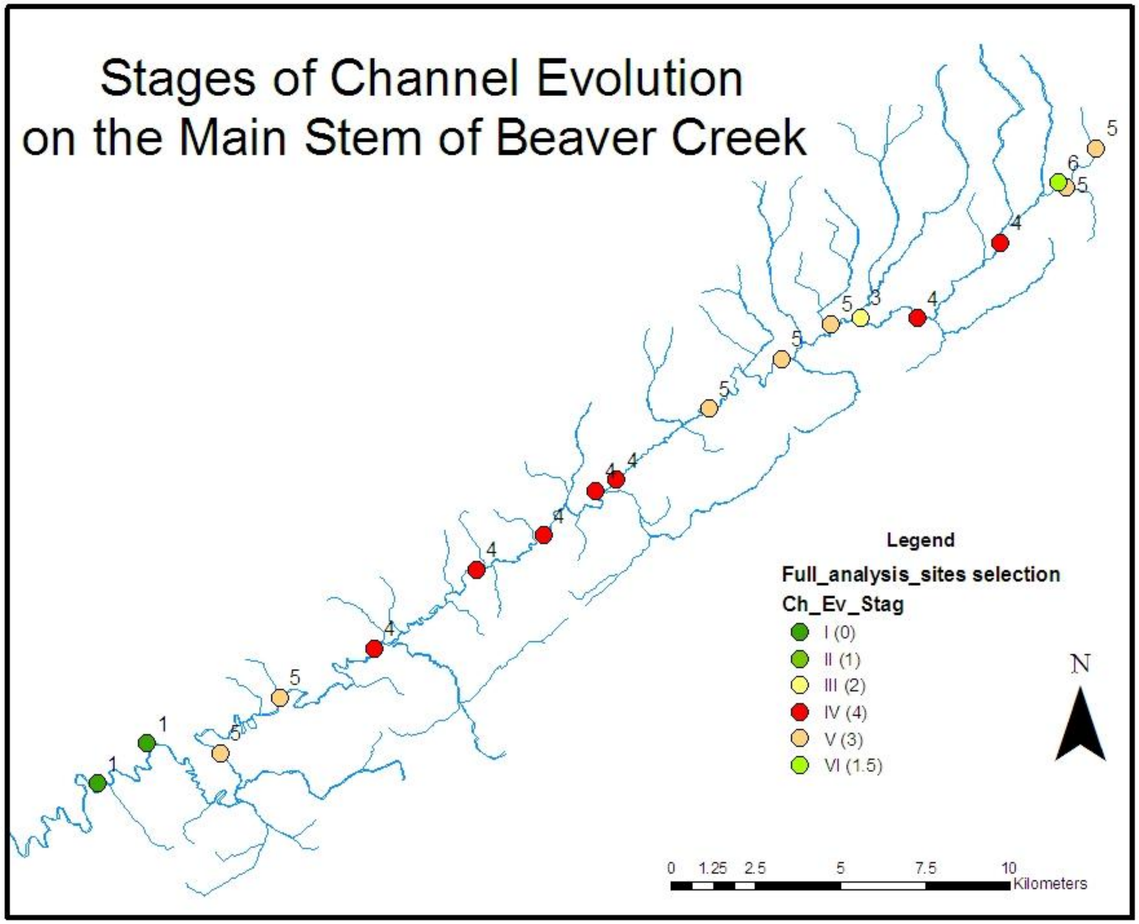


Figure 20 - Stages of Channel Evolution on the Main Stem of Beaver Creek

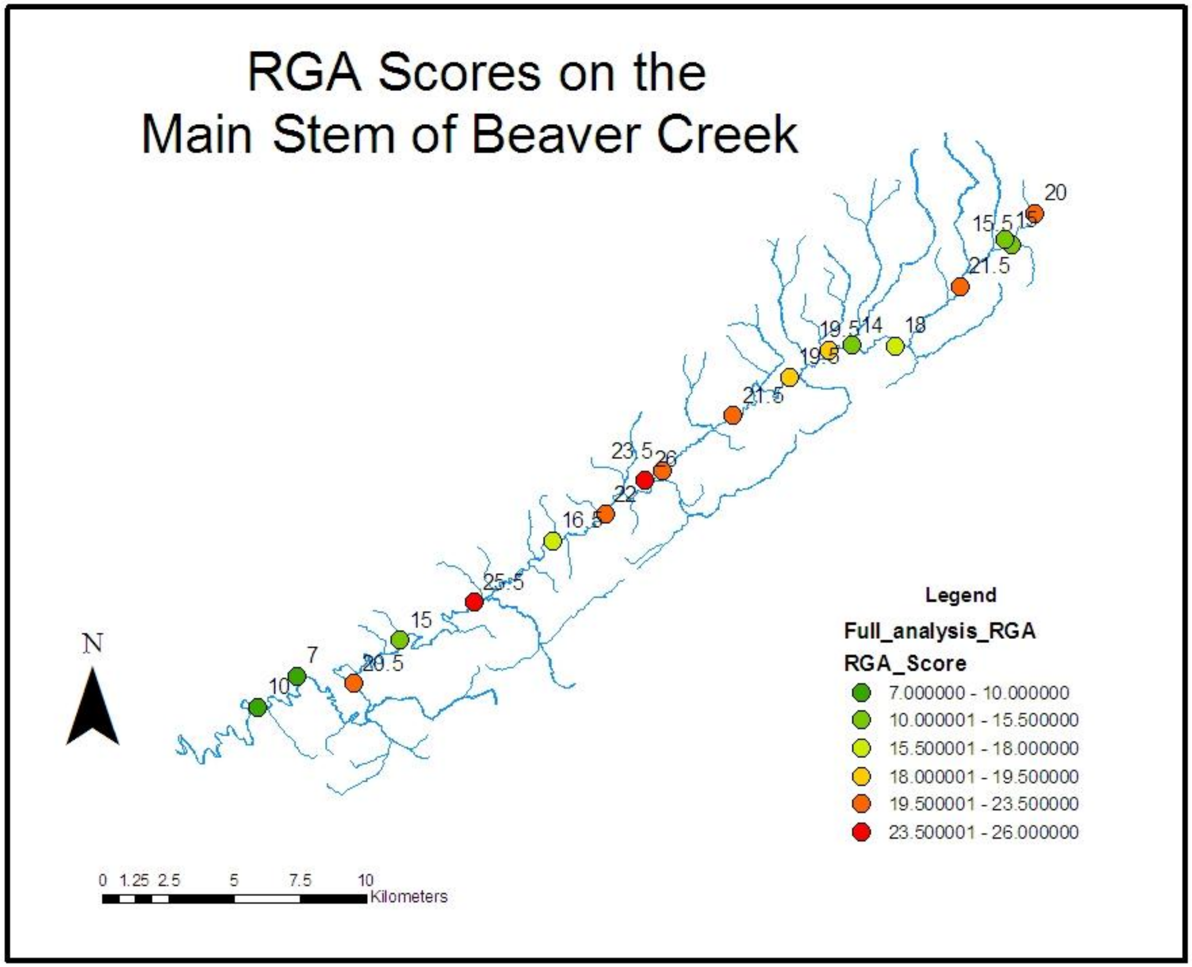


Figure 21 - RGA Scores on the Main Stem of Beaver Creek

Table 13 - Measured Variables on the Main Stem of Beaver Creek

Stream	Site ID	D50	% Catchment Developed	% Local Developed	% Catchment Forrested	% Impervious	Bed Material	Incision	Left Instability
Beaver	35	0.033	29.26%	47.70%	27.22%	9.18%	4	2	1.5
Beaver	39	11	39.77%	29.63%	26.07%	12.02%	2	3	2
Beaver	40	24	40.13%	58.38%	26.31%	12.16%	2	2	1
Beaver	41	61	40.77%	32.95%	26.33%	12.45%	1	2	0
Beaver	42	14	40.53%	31.78%	26.55%	12.40%	0	1	0
Beaver	43	0.033	38.85%	44.19%	27.11%	11.91%	4	3	1.5
Beaver	46	0.033	32.73%	44.64%	28.11%	10.26%	4	2	2
Beaver	47	0.033	34.54%	56.75%	26.77%	10.71%	4	1	1.5
Beaver	48	5	25.27%	30.57%	28.78%	8.13%	2	2	2
Beaver	49	0.033	26.16%	31.74%	29.05%	8.21%	4	2	2
Beaver	50	6	37.51%	78.80%	26.80%	11.56%	3	1.5	0
Beaver	a						3	3	0.5
Beaver	b						3	1	0
Beaver	c						4	2	1.5
Beaver	d						3	2	1.5
Beaver	e						3	0	0
Beaver	f						4	2	0.5
Beaver	g						3	2	0
Beaver	h						4	2	2
Beaver	i						3	2	0.5

Table 14 - Measured Variables on the Main Stem of Beaver Creek

Stream	Site ID	Right Instability	Instability	Left Vegetation	Right Vegetation	Vegetation	Bank Accretion	SCE Score	RGA Score	Slope (ft/1000ft)
Beaver	35	1	2.5	1.5	1	2.5	3.5	4	23.5	0.002
Beaver	39	1.5	3.5	1	0.5	1.5	2.5	3	20.5	0.025
Beaver	40	0.5	1.5	0	0.5	0.5	3	3	15	0.021
Beaver	41	0	0	0	0	0	3	0	7	0.074
Beaver	42	1	1	1	1.5	2.5	3.5	0	10	0.006
Beaver	43	1.5	3	1.5	1	2.5	4	4	25.5	0
Beaver	46	2	4	1.5	1.5	3	4	4	26	0.005
Beaver	47	1.5	3	0.5	0.5	1	4	4	22	0.001
Beaver	48	0.5	2.5	1.5	1.5	3	3	3	19.5	0.004
Beaver	49	1.5	3.5	0.5	1	1.5	3.5	3	21.5	0.001
Beaver	50	0.5	0.5	0.5	0	0.5	4	4	16.5	0.001
Beaver	a	1.5	2	2	1	3	2.5	4	21.5	
Beaver	b	0	0	1	2	3	1.5	2	13.5	
Beaver	c	0	1.5	0	0.5	0.5	1.5	2	15.5	
Beaver	d	1	2.5	1.5	1.5	3	2.5	3	20.5	
Beaver	e	0	0	1	1.5	2.5	3.5	4	18	
Beaver	f	1	1.5	1.5	2	3.5	4	2	24	
Beaver	g	0	0	1	1.5	2.5	3.5	2	17	
Beaver	h	1	3	2	0.5	2.5	3	4	21.5	
Beaver	i	0	0.5	0	1	1	0.5	4	15	

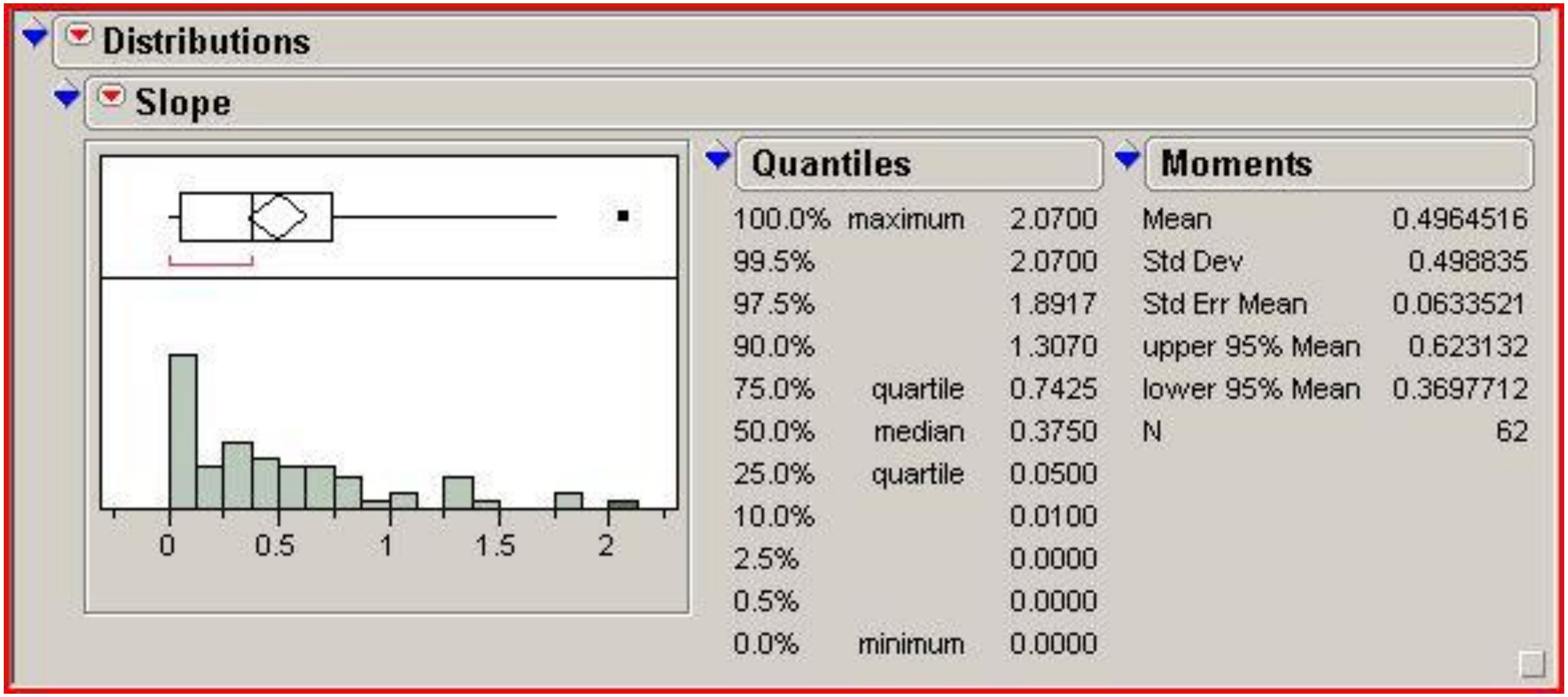
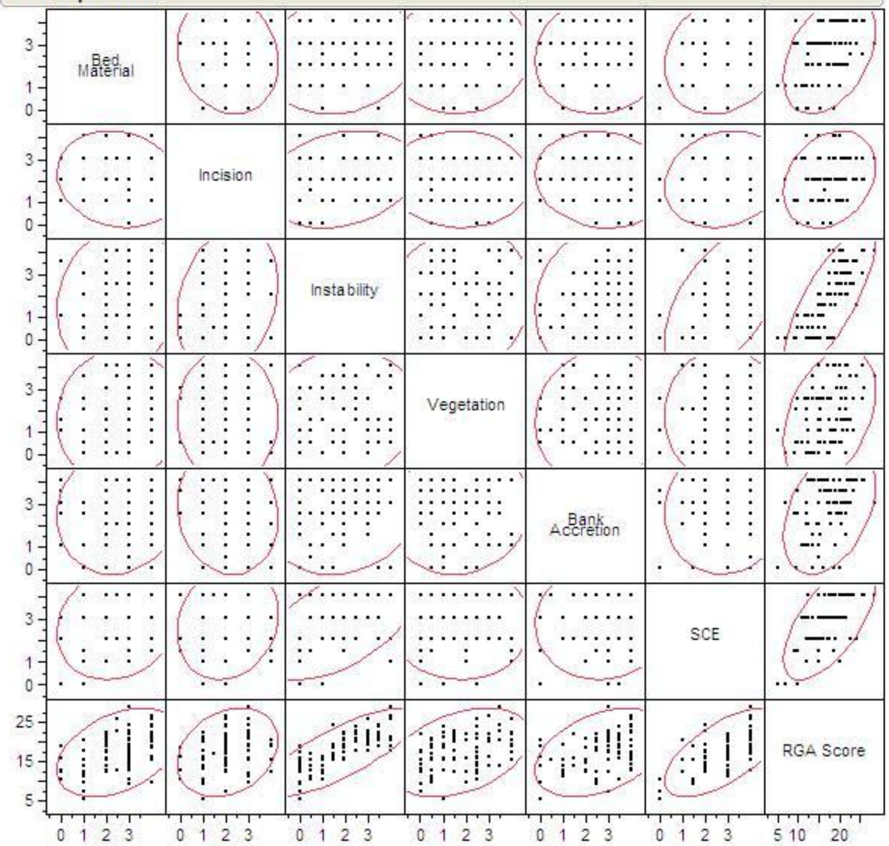


Figure 22 - Distribution of Slope Values in Percent

Multivariate

Scatterplot Matrix



Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob
Incision	Bed Material	-0.1385	91	0.1904
Instability	Bed Material	0.1354	91	0.2008
Instability	Incision	0.2336	91	0.0259*
Vegetation	Bed Material	0.0538	91	0.6127
Vegetation	Incision	-0.0267	91	0.8017
Vegetation	Instability	0.1082	91	0.3071
Bank Accretion	Bed Material	0.0928	91	0.3815
Bank Accretion	Incision	-0.1111	91	0.2945
Bank Accretion	Instability	0.1284	91	0.2252
Bank Accretion	Vegetation	0.0981	91	0.3548
SCE	Bed Material	0.1864	91	0.0769
SCE	Incision	0.1623	91	0.1242
SCE	Instability	0.5538	91	<.0001*
SCE	Vegetation	-0.0128	91	0.9041
SCE	Bank Accretion	0.0286	91	0.7879
RGA Score	Bed Material	0.4011	91	<.0001*
RGA Score	Incision	0.2607	91	0.0126*
RGA Score	Instability	0.7852	91	<.0001*
RGA Score	Vegetation	0.3802	91	0.0002*
RGA Score	Bank Accretion	0.4058	91	<.0001*
RGA Score	SCE	0.6496	91	<.0001*

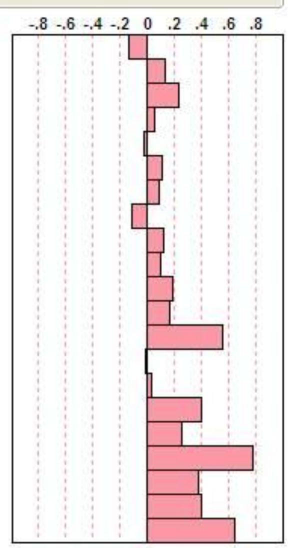
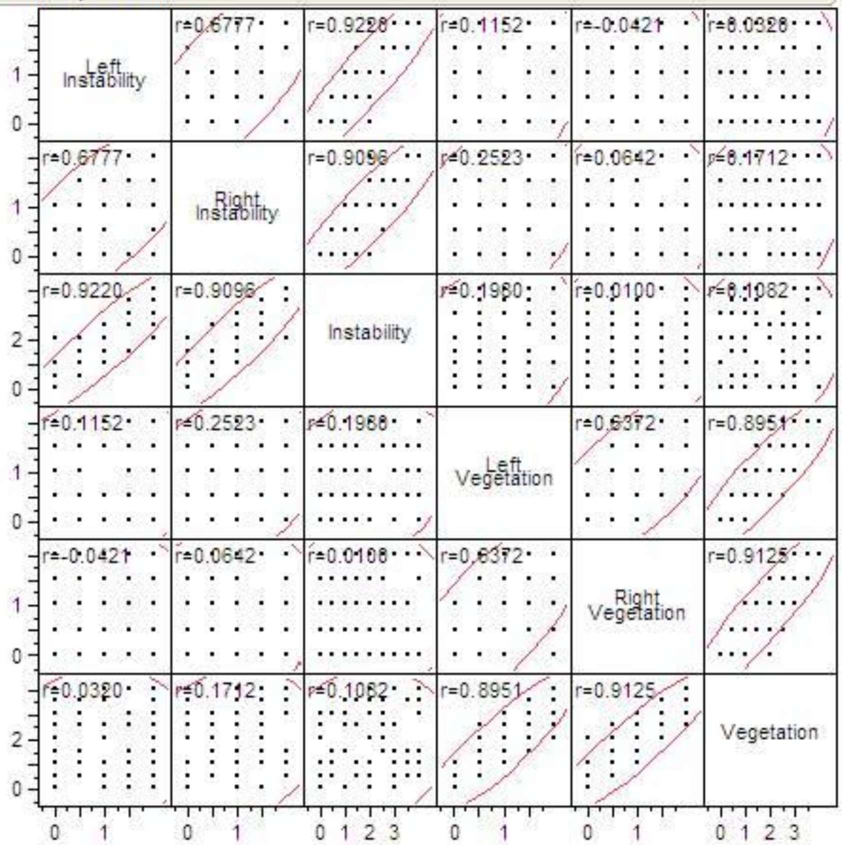


Figure 23 - Scatterplot Matrix and Pairwise Correlation Analysis of RGA Variables collected at All RGA Sites

Multivariate

Scatterplot Matrix



Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob
Right Instability	Left Instability	0.6777	91	<.0001*
Instability	Left Instability	0.9220	91	<.0001*
Instability	Right Instability	0.9096	91	<.0001*
Left Vegetation	Left Instability	0.1152	91	0.2768
Left Vegetation	Right Instability	0.2523	91	0.0158*
Left Vegetation	Instability	0.1980	91	0.0599
Right Vegetation	Left Instability	-0.0421	91	0.6920
Right Vegetation	Right Instability	0.0642	91	0.5458
Right Vegetation	Instability	0.0100	91	0.9251
Right Vegetation	Left Vegetation	0.6372	91	<.0001*
Vegetation	Left Instability	0.0320	91	0.7632
Vegetation	Right Instability	0.1712	91	0.1047
Vegetation	Instability	0.1082	91	0.3071
Vegetation	Left Vegetation	0.8951	91	<.0001*
Vegetation	Right Vegetation	0.9125	91	<.0001*

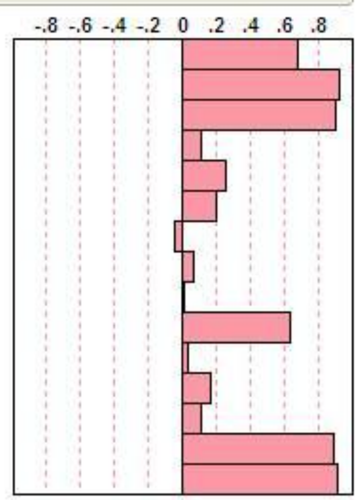
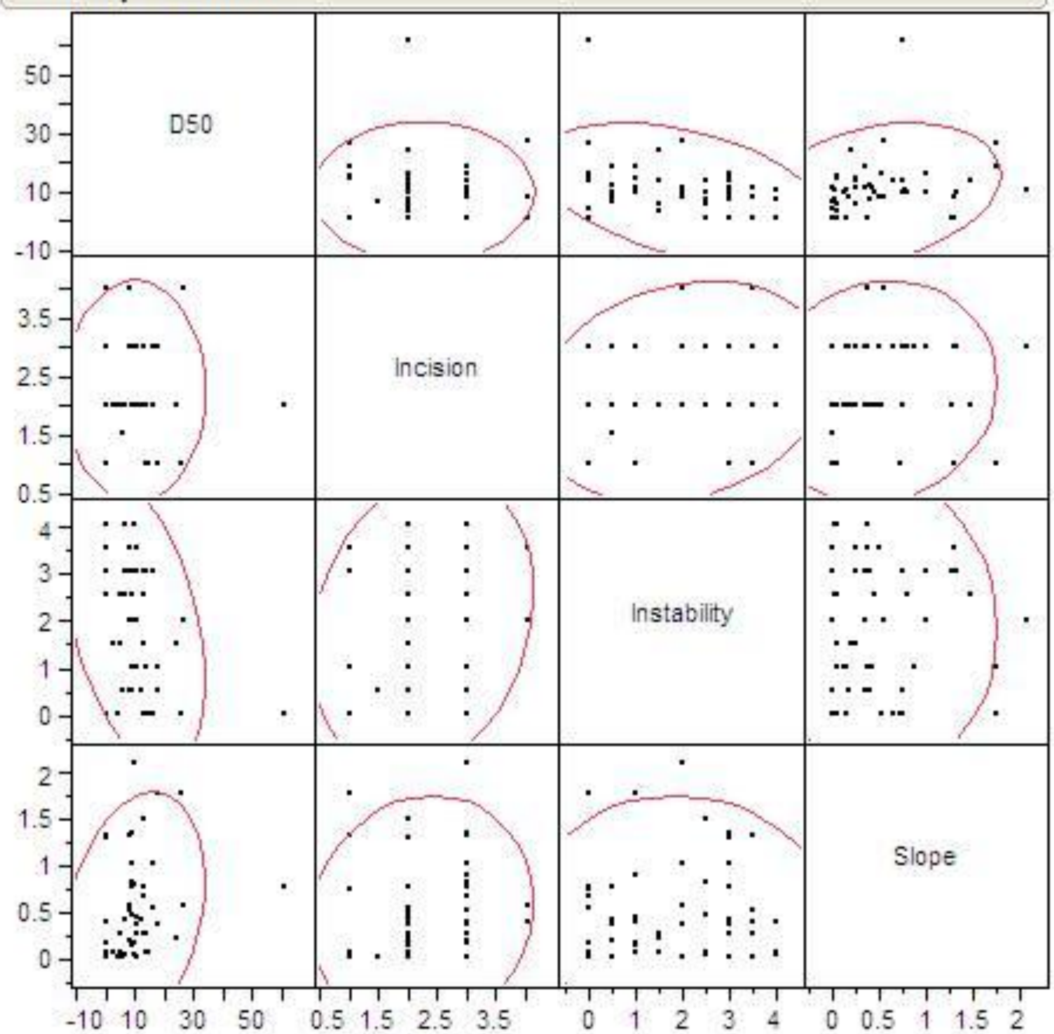


Figure 24 - Multivariate Correlation Plots Comparing Stream Bank Vegetation Scores and Stream Bank Instability Scores

Multivariate

Scatterplot Matrix



Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob
Incision	D50	-0.0003	52	0.9981
Instability	D50	-0.4179	52	0.0020*
Instability	Incision	0.1990	57	0.1378
Slope	D50	0.2590	53	0.0611
Slope	Incision	0.0932	57	0.4903
Slope	Instability	-0.0453	57	0.7382

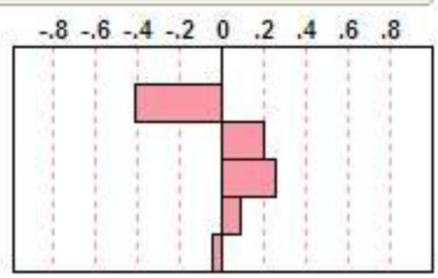


Figure 25 – Correlations Between Slope, Particle Size, Incision and Instability

Chapter 7 Discussion

None of the stream channels in the sub-watersheds in the Beaver Creek watershed showed discernable patterns in the stages of channel evolution observed along their courses of flow. The main stem of Beaver Creek did appear to show a pattern of adjustment, which was similar to that reported in Simon and Rinaldi (2000) for West Tarkio Creek, a stream of similar length to Beaver Creek, and along which a similar number of sites were evaluated (Figure 26).

The degree of watershed urbanization, watershed imperviousness and watershed forestation did not appear to have an impact on the Channel Stability Index of a given site. While none of the RGA metrics directly accounted for watershed urbanization, several of them (Bed/Bank Protection, Degree of Constriction and Woody Riparian Vegetation) would likely be negatively impacted by watershed development. Thus, it was unexpected that the stability index would have no discernable relationship with urbanization.   Given the evidence presented in the literature that watershed urbanization does have a strong effect on stream bank stability, it is more likely that the Rapid Geomorphic Assessment is simply not suited to measuring system-wide stream channel stability on the watershed scale under a condition of rapid urbanization. That said, it remains a valuable tool for comparing channel stability at reach-scale sites within a watershed.

It was expected that reach scale (defined here as a length of stream channel equal to six to ten channel widths.) water surface slope would have a controlling

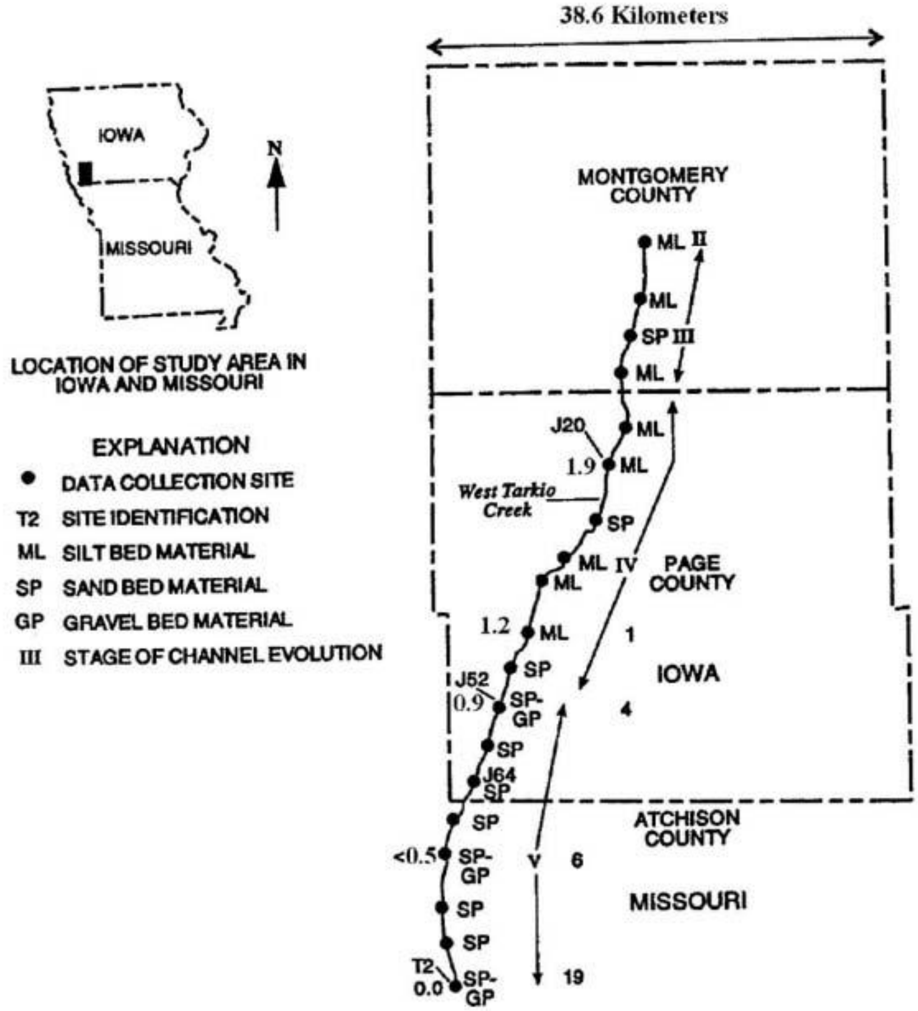


Fig. 9. Map of West Tarkio Creek showing stages of channel evolution, dominant bed-material size class, age of oldest riparian tree (years, numbers on right) and widening rate (m/y, numbers on left). Note systematic trends of stage of channel evolution, rates of widening and age of oldest riparian species with distance upstream (from Simon and Rinaldi, 2000).

Figure 26 - Map of West Tarkio Creek (Simon and Rinaldi, 2000)

influence on channel stability. As reported in Simon (1992), stream power (Equation 3) should have been able to be used to predict the magnitude of a channel's response to disturbance. In this study, since stream velocity was not measured, but was assumed to increase with flow rate in a similar manner at all sites, velocity was taken as a surrogate for unit stream power. However, no correlation was observed between slope and any of the RGA metrics. In fact, a site on Willow Creek had one of the highest slopes (1.76%) but also the lowest RGA score (5). This site was very near the headwater and as such had a relatively small contributing area of about 190 acres. The vicinity of the stream showed no recent alteration and little upstream development. Also, the site had large bed material, receiving an RGA score of 1 (boulder/cobble) and having a particle d50 of 26mm and a mean particle size of 96.61mm. In general, the sites studied had low slopes, ranging from 0% (unobservable) to 2.07%, with a mean of about 0.5%. (See Figure 22.)

Pizzuto (2000) finds channels adjust until hydraulic roughness (quantified by measuring channel width, depth, sinuosity and bed material particle size) is low enough to accommodate flows, though in that study the differences in bed material particle size between rural and urban streams were subtle. Strong negative correlation was found between bed particle d50 and RGA score ($r = -0.6039$, $p < 0.0001$) and positive correlation existed between the Bed Material metric and the RGA score ($r = 0.4690$, $p = 0.0002$), showing that as the average size of the bed material at a site decreased, the likelihood of channel instability would increase. When the watersheds are broken down into Low, Medium and High degrees of development, the watersheds with Low development averaged a particle size of 9.61 mm, watersheds with Medium development averaged 10.55 mm and High development watersheds averaged 10.88 mm. (Appendix H) Despite the slight trend towards larger particle size in areas of higher development, the 1.27 mm difference between smallest average and largest average is probably not a direct product of the difference between lowest average watershed development (19.85%) and highest average watershed development (63.09%).

As shown in Appendix C and Appendix D, the particle size of channel bed material was the evaluated metric most likely to correlate with channel instability. This suggests that, for a given flow rate, the ability of a channel's bed material to resist entrainment in flow is a better predictor of channel instability than the energy available to move sediment, which is the result that would have been suggested if water surface slope had a better correlation with channel instability.

Simon and Rinaldi (2006), in an examination of rivers flowing through substrates of different sizes and responding to different anthropogenic disturbances, responded in similar ways, but ultimately achieved channel stability in different forms. These results were supported by computer simulations that explored how channels whose beds and banks were composed of sand, silt and clay would respond to a 50% reduction of upstream sediment inputs.

Since the assumption that "the bed and banks are free to adjust to imposed changes and successive stages of evolution are not interrupted by other disturbances." (Simon, 1989) cannot reasonably be made in the context of a rapidly urbanizing watershed, the Channel Evolution Model cannot account for the dynamic nature of channel disturbance and adjustment in that situation. The steady, predictable, upstream and downstream progression of channel adjustment cannot occur in situations in which further disturbances interrupt the process. Additionally, the definition of the premodified stage relied, in part, on comparisons to “the upstream-most reaches of present day (1987) adjusting networks, and the nonchannelized Hatchie River”, thus introducing some of the uncertainties of the form-based assessment techniques, at least in watersheds undergoing rapid urbanization. So as to account for this complexity, Gregory (2002) and Chin (2005) propose breaking stream networks in urbanizing watersheds into segments defined by road crossings, drainage culverts and other structures or features that would interrupt the migration of knickpoints. Their approach was one part of a broader watershed management policy that did not include rapid geomorphic assessments.

However, as shown in Figure 27 from Simon (1989), in an undeveloped, agricultural watershed with non-cohesive sediments, areas of degradation and aggradation can be clearly observed to proceed upstream and downstream of an area of maximum disturbance. In figure 27, b is a dimensionless exponent used in the equation

Equation 4 - Power Function Describing Bed Level Adjustment

$$E = a(t)^b$$

In which “E is the elevation of the bed for a given year above sea level; a is a coefficient

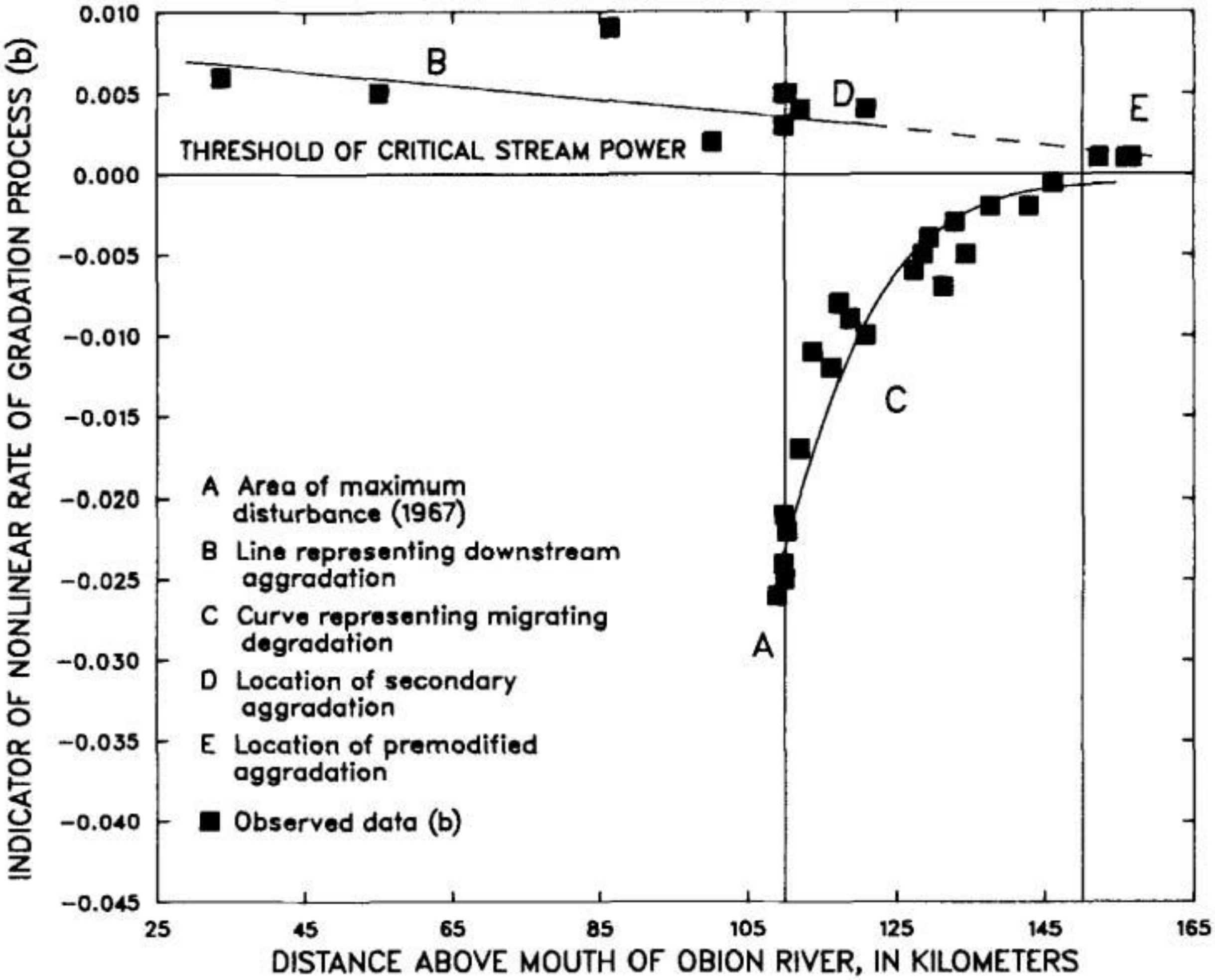


Figure 27 – Model of Bed-Level Response in the Obion River System (Simon, 1989)

determined by regression representing the premodified elevation of the bed, in meters above sea level; t is the time since beginning of adjustment process, in years, where $t_0 = 1 * 0$; and b is a dimensionless exponent, determined by regression and indicative of the nonlinear rate of chance on the bed." (Simon, 1989) When b values are positive, there is aggradation taking place. When b values are negative, degradation is occurring.

The Channel Evolution Model also assumes that "there is no local bedrock control of bed-level". Exposed bedrock was encountered at many of the study sites (at four of which it was the primary bed material) and is a characteristic of streams in the ridge and valley ecoregion (USEPA, 2002). The presence of bedrock would interrupt the movement of "knickpoints" and "knickzones" that, in the channel evolution model would move upstream of a disturbed area.

It was expected that stream channel incision would be heavily influenced by bed material, and that incision in turn would exert a strong influence on bank instability, but the results did not support this hypothesis. As shown in Fig 25, there was almost no correlation between bed material and incision or incision and instability. There did appear to be weak correlation between bed particle size and instability. Measurements of incision were made at the deepest spot along the reach, which frequently was the bottom of pool that was significantly deeper than the average depth along the reach.

Since an innumerable number of anthropogenic artificial pools were created by drainage pipes, debris, constrictions and other adjustments to the landscape, a measurement of the absolute deepest point along a reach may be misleading in urbanizing watersheds. Also, stream banks in the Beaver Creek Watershed are typically composed of cohesive silt and clay, which allows them to maintain stability at higher angles (and thus, more incised channels) than would be possible in a sand bed river system. While this suggests that channel bottoms were not being actively degraded, it does not clearly reflect bank height relative to average flow depth.

The amount of developed land and impervious surfaces in a watershed is not the only land use factor that can contribute to stream bank instability. In a review of existing studies, Belesky et al. (1999) found that widespread livestock grazing, when the animals are allowed access to riparian areas, has impacts on the local and watershed scale. The studies reviewed focused mostly on the negative impacts of the grazing on stream habitat, which included siltation and loss of bank vegetations. White and Greer (2005), however, found that riparian vegetation actually improved in a watershed near San Diego, CA as it underwent urbanization, due in part to a decrease in land devoted to livestock grazing, and an increase in the affected area and frequency of inundation during flood events.

The presence of vegetation on streambanks has been shown to have a stabilizing effect. (Simon, 2002; Wynn 2004, 2006) As such, it was expected that sites with a high percentage of their banks covered by woody vegetation would correspond well with sites that had low bank instability scores. As shown in Figure 24, this relationship was not observed in this study. Only established woody vegetation was considered in the assessment, as a surrogate for bank roughness. Studies have shown that plant roots can have a significant stabilizing effect on stream banks. They serve to increase the tensional and shear strength of soils, as well as proving mechanical reinforcement and buttressing. These contributions have a greater effect on overall bank stability than the retarding effect woody vegetation has on the power of stream flows (Simon, 2002). As such, the presence or absence of other plants (or, during non-growing seasons, evidence of their presence during times of suitable climate) on stream banks should have been considered.

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Appendices

Appendix A The Rapid Geomorphic Assessment field survey form.

CHANNEL-STABILITY RANKING SCHEME

River____________________ **Site Identifier**____________________________

Date __________ **Time**______ **Crew** ____________ **Samples Taken**____________________

Pictures (circle) U/S D/S X-section **Slope**________ **Pattern:** Meandering Straight Braided

1. Primary bed material

Bedrock	Boulder/Cobble	Gravel	Sand	Silt Clay
0	1	2	3	4

_____

2. Bed/bank protection

Yes	No	(with)	1 bank protected	2 banks
0	1		2	3

_____

3. Degree of incision (Relative elevation of "normal" low water; floodplain/terrace @ 100%)

0-10%	11-25%	26-50%	51-75%	76-100%
4	3	2	1	0

_____

4. Degree of constriction (Relative decrease in top-bank width from up to downstream)

0-10%	11-25%	26-50%	51-75%	76-100%
0	1	2	3	4

_____

5. Stream bank erosion (Each bank)

	None	Fluvial	Mass wasting (failures)	
Left	0	1	2	_____
Right	0	1	2	_____

6. Stream bank instability (Percent of each bank failing)

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	0	0.5	1	1.5	2	_____
Right	0	0.5	1	1.5	2	_____

7. Established riparian woody-vegetative cover (Each bank)

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	2	1.5	1	0.5	0	_____
Right	2	1.5	1	0.5	0	_____

8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)

	0-10%	11-25%	26-50%	51-75%	76-100%	
Left	2	1.5	1	0.5	0	_____
Right	2	1.5	1	0.5	0	_____

9. Stage of channel evolution

I	II	III	IV	V	VI
0	1	2	4	3	1.5

_____

Total Score _______

Notes:

Appendix B RGA scores, geographic coordinates and other assessments for evaluated sites.

Stream	Lat	Long	FID	D50	% Catchment Developed	% Local Developed	% Catchment Forrested	% Impervious	Bed Material
Knob	36.02942	-83.9813	0	11	58.72%	59.00	38.90%	16.30%	2
Knob	36.03187	-83.9747	1	9	58.55%	63.76	40.21%	17.53%	2
Knob	36.03502	-83.9665	2	16	55.99%	55.99	42.91%	14.92%	3
Knob	36.02567	-83.9907	3	14	58.72%	68.69	38.90%	16.30%	2
Knob	36.03699	-84.0022	4	11	59.62%	59.97	36.23%	18.68%	2
Knob	36.02552	-83.9922	a						2
Knob	36.02537	-83.9936	b						2
Knob	36.02646	-83.9957	c						3
Knob	36.02751	-83.997	d						2
Knob	36.0332	-83.997	e						1
Knob	36.03488	-83.9992	f						3
Knob	36.03768	-84.0039	g						2
Knob	36.03771	-84.0045	h						3
Knob	36.02464	-83.9878	i						1
Knob	36.02531	-83.9886	j						0
Knob	36.02571	-83.9893	k						3
Meadow	35.9639	-84.1285	5	11	47.78%	83.98	30.72%	14.09%	2.5
Meadow	35.96428	-84.095	6	9	33.32%	33.32	40.56%	8.49%	3
Meadow	35.96003	-84.1029	7		37.69%	53.28	35.57%	9.52%	4
Meadow	35.96527	-84.119	8	18	43.59%	52.77	34.72%	11.40%	1
Grassy	35.97491	-84.0743	9	11	53.47%	52.47	35.69%	13.83%	2
Grassy	35.97822	-84.0645	10	9	45.25%	42.14	38.07%	12.70%	2.5
Meadow	35.9625	-84.1093	11						
Grassy	35.98538	-84.0592	12	10	46.17%	40.46	35.22%	14.83%	2
Grassy	35.98728	-84.0597	13	0.033	46.30%	49.30	35.15%	14.75%	4
Grassy	35.98035	-84.0603	14	7	41.27%	28.46	36.40%	11.36%	3
Grassy	35.99611	-84.0386	15	16	56.32%	56.32	26.92%	25.18%	2
Grassy	35.98701	-84.05	16	12	53.18%	47.58	31.46%	19.58%	2
Grassy	35.9921	-84.0455	17	13	55.23%	51.57	27.63%	22.51%	2
Grassy	35.98346	-84.0591	a						3
Plumb	35.94647	-84.1272	18	10	62.10%	62.10	31.80%	15.48%	2
Plumb	35.95306	-84.1245	19	13	64.57%	61.96	21.48%	19.64%	2
Plumb	35.95834	-84.1302	20	13	63.40%	45.46	22.92%	19.56%	1
Plumb	35.9506	-84.1229	21	8	66.61%	67.72	20.66%	20.86%	0
Plumb	35.94952	-84.1122	22	8	63.34%	63.34	22.16%	20.55%	3
Plumb	35.9501	-84.1195	a						4
Plumb	35.94795	-84.1237	b						2
Plumb	35.9518	-84.123	c						3

Stream	Lat	Long	FID	D50	% Catchment Developed	% Local Developed	% Catchment Forrested	% Impervious	Bed Material
Hines	36.05943	-83.9271	23	8	72.74%	72.74	25.39%	21.31%	1
Hines	36.06877	-83.9433	24	7	66.25%	43.90	29.59%	21.13%	2.5
Hines	36.06706	-83.9306	25	13	71.32%	56.59	26.59%	22.47%	2
Hines	36.06593	-83.9265	26	9	72.28%	71.80	25.71%	21.55%	3
Hines	36.06754	-83.9291	27	9	71.70%	61.22	26.32%	22.17%	2
Hines	36.06735	-83.934	a						3
Hines	36.06694	-83.9321	b						3
Hines	36.06721	-83.9279	c						1
Hines	36.06432	-83.9261	d						2
Willow	36.12764	-83.8913	28	26	12.90%	8.59	19.49%	4.68%	1
Willow	36.11807	-83.8879	29		10.92%	7.14	23.19%	4.20%	3
Willow	36.0832	-83.9249	30		17.23%	18.64	32.89%	5.82%	4
Willow	36.08664	-83.9212	a						3
Willow	36.0858	-83.911	b						3
Willow			31						
Willow			32						
Willow			33						
Beaver	36.082	-83.9244	34	4	22.46%	53.45	31.84%	7.18%	3
Beaver	36.04035	-84.005	35	0.033	29.26%	47.70	27.22%	9.18%	4
Beaver	36.12419	-83.8449	36	0.033	14.30%	14.30	12.90%	4.98%	4
Beaver	36.10002	-83.8773	37	7	15.24%	14.65	26.81%	5.73%	3
Beaver	36.11416	-83.8551	38	10	13.39%	13.30	29.17%	5.49%	0
Beaver	35.97023	-84.1382	39	11	39.77%	29.63	26.07%	12.02%	2
Beaver	35.98551	-84.1168	40	24	40.13%	58.38	26.31%	12.16%	2
Beaver	35.97441	-84.1605	41	61	40.77%	32.95	26.33%	12.45%	1
Beaver	35.96375	-84.1776	42	14	40.53%	31.78	26.55%	12.40%	0
Beaver	35.99747	-84.0845	43	0.033	38.85%	44.19	27.11%	11.91%	4
Beaver	36.11555	-83.8578	44	27	22.22%	28.48	14.98%	7.50%	1
Beaver	36.08078	-83.9051	45	3	20.00%	25.03	32.34%	6.62%	4
Beaver	36.03772	-84.0125	46	0.033	32.73%	44.64	28.11%	10.26%	4
Beaver	36.02633	-84.0294	47	0.033	34.54%	56.75	26.77%	10.71%	4
Beaver	36.07115	-83.9503	48	5	25.27%	30.57	28.78%	8.13%	2
Beaver	36.05851	-83.9743	49	0.033	26.16%	31.74	29.05%	8.21%	4
Beaver	36.01775	-84.0517	50	6	37.51%	78.80	26.80%	11.56%	3
Beaver	36.07982	-83.9332	51	0.033	22.04%	72.20	31.84%	7.28%	4
Beaver	36.10142	-83.8775	a						3
Beaver	36.07934	-83.9173	b						3
Beaver	36.07929	-83.9175	c						4
Beaver	36.07947	-83.9196	d						3
Beaver	36.07996	-83.9206	e						3
Beaver	36.07998	-83.921	f						4

Stream	Lat	Long	FID	D50	% Catchment Developed	% Local Developed	% Catchment Forrested	% Impervious	Bed Material
Beaver	36.07997	-83.9217	g						3
Beaver	36.0802	-83.922	h						4
Beaver	36.08023	-83.923	i						3
Cox	36.07962	-83.8867	52	0.033	14.63%	21.34	46.00%	4.92%	4
Cox	36.08538	-83.8743	53	8	11.62%	11.62	44.46%	4.22%	4
Cox	36.07054	-83.9021	54	5	60.44%	60.44	34.57%	15.54%	3
Cox	36.07903	-83.8984	55	10	27.33%	38.67	43.61%	7.71%	
North Forl	36.08155	-83.9362	56	0.033	42.18%	42.18	14.14%	12.29%	4
Mill	36.08865	-83.9201	57	9	18.24%	18.24	37.26%	6.07%	2
Haw	36.0221	-83.9961	58	15	61.42%	64.33	31.04%	23.11%	2
Haw	36.01491	-84.0093	59		60.06%	69.39	22.51%	25.95%	0
Haw	36.01612	-84.0043	60		60.45%	60.73	30.95%	21.27%	2
Kerns	36.14042	-83.8799	61	18	7.60%	7.60	54.61%	3.46%	1
Annon Tri	36.0792	-83.9173	a						3
Annon Tri	36.07825	-83.916	b						3
Annon Tri	36.07867	-83.9192	c						4
Annon Tri	36.09825	-84.0583	d						3

Stream	FID	Incision	Left Instability	Right Instability	Instability	Left Vegetation	Right Vegetation	Vegetation	Bank Accretion	SCE	RGA Score	Slope
Knob	0	2	1.5	1.5	3	2	2	4	1.5	4	21.5	0.35
Knob	1	3	1	1	2	2	2	4	4	4	22	1
Knob	2	2	0	0	0	0	0	0	4	2	14	0.53
Knob	3	2	1.5	1.5	3	1	0.5	1.5	3.5	4	21	0.25
Knob	4	2	1	1	2	0	0	0	3	3	17	0
Knob	a	3	2	1.5	3.5	1	0.5	1.5	3	4	22	
Knob	b	2	1.5	2	3.5	0.5	1	1.5	2.5	4	20.5	
Knob	c	1	2	2	4	2	2	4	4	1	20	
Knob	d	2	2	2	4	1	0.5	1.5	3	2	17.5	
Knob	e	2	0	0	0	1	1	2	3	1	12	
Knob	f	1	0	0	0	1.5	1	2.5	4	2	15.5	
Knob	g	4	0	0	0	0	0	0	2	1	12	
Knob	h	0	0	0	0	0.5	0	0.5	4	2	12.5	
Knob	i	2	2	0	2	2	1.5	3.5	2.5	4	20	
Knob	j	2	0.5	0.5	1	1	0.5	1.5	2.5	2	12	
Knob	k	1	0	0	0	0	0	0	4	2	13	
Meadow	5	2	1	0	1	0	0	0	2	4	12.5	0.42
Meadow	6	3	1.5	1.5	3	1	0.5	1.5	3	4	22.5	1.32
Meadow	7	2	1.5	2	3.5	0.5	0.5	1	4	4	23.5	0.51
Meadow	8	3	0.5	0	0.5	0.5	0	0.5	1	3	11	0.36
Grassy	9	3	1	1	2	0.5	1.5	2	1.5	2	15.5	0.36
Grassy	10	3	1	1.5	2.5	1.5	2	3.5	4	2	22.5	0.79
Meadow	11											0.78
Grassy	12	2	2	2	4	0.5	0.5	1	3	4	21	0.02
Grassy	13	1	1.5	2	3.5	1	0.5	1.5	3	3	21	1.3
Grassy	14	2	1.5	1.5	3	1.5	1	2.5	2	3	20.5	0.4
Grassy	15	3	1.5	1.5	3	0.5	0.5	1	3	4	21	1.01
Grassy	16	2	0.5	0	0.5	0.5	0.5	1	1	3	12.5	0.39
Grassy	17	2	1	1.5	2.5	2	0	2	2.5	3	20	1.47
Grassy	a	1	2	2	4	0	0.5	0.5	3	4	20.5	0
Plumb	18	3	0	2	2	1	2	3	3.5	4	20.5	2.07
Plumb	19	2	1	0.5	1.5	0	1	1	3.5	4	19	0.24
Plumb	20	3	0	0	0	0.5	0	0.5	2.5	1.5	9.5	0.64
Plumb	21	3	2	1.5	3.5	1	0	1	3	3	18.5	0.5
Plumb	22	4	1	1	2	2	2	4	1	2	19	0.56
Plumb	a	1	0.5	1	1.5	1	1.5	2.5	0	3	16	
Plumb	b	3	2	2	4	0.5	0	0.5	0	4	18.5	
Plumb	c	3	1.5	1.5	3	0	0	0	3.5	4	21.5	

Stream	FID	Incision	Left Instability	Right Instability	Instability	Left Vegetation	Right Vegetation	Vegetation	Bank Accretion	SCE	RGA Score	Slope
Hines	23	3	2	1	3	0	0	0	2.5	4	17.5	1.31
Hines	24	2	2	2	4	2	2	4	4	4	25.5	0.03
Hines	25	3	2	1	3	0.5	0	0.5	3.5	4	19	0.74
Hines	26	2	1	0	1	0.5	2	2.5	0	3	13.5	0.12
Hines	27	2	0	0.5	0.5	1.5	1.5	3	1	3	13.5	0.75
Hines	a	2	1	1	2	0.5	0.5	1	2	3	18	
Hines	b	0	0.5	0	0.5	0	0.5	0.5	2.5	1.5	10	0.75
Hines	c	3	0	1	1	1.5	1	2.5	1	3	11.5	0.12
Hines	d	2	0	0	0	2	2	4	4	2	17	
Willow	28	1	0	0	0	0.5	0.5	1	0	0	5	1.76
Willow	29	3	2	2	4	1.5	2	3.5	3	4	28.5	0.38
Willow	30	1	0	0	0	0.5	1.5	2	0	1.5	9.5	0.72
Willow	a	1	1.5	1	2.5	0.5	1	1.5	2.5	3	17.5	
Willow	b	1	0	0	0	0	0	0	2.5	1.5	9	
Willow	31											0.01
Willow	32											0.34
Willow	33											0.64
Beaver	34	2	0	0	0	0	0	0	4	2	14	0.01
Beaver	35	2	1.5	1	2.5	1.5	1	2.5	3.5	4	23.5	0.02
Beaver	36	4	1.5	2	3.5	0.5	0	0.5	0	3	20	0.37
Beaver	37	2	1	1.5	2.5	1.5	0.5	2	3	4	21.5	0.02
Beaver	38	2	0	1	1	0.5	1	1.5	4	3	15.5	0.16
Beaver	39	3	2	1.5	3.5	1	0.5	1.5	2.5	3	20.5	0.25
Beaver	40	2	1	0.5	1.5	0	0.5	0.5	3	3	15	0.21
Beaver	41	2	0	0	0	0	0	0	3	0	7	0.74
Beaver	42	1	0	1	1	1	1.5	2.5	3.5	0	10	0.06
Beaver	43	3	1.5	1.5	3	1.5	1	2.5	4	4	25.5	0
Beaver	44	4	1	1	2	0	0.5	0.5	3	1.5	15	0.56
Beaver	45	2	0.5	1	1.5	0	0.5	0.5	2.5	4	18	0.04
Beaver	46	2	2	2	4	1.5	1.5	3	4	4	26	0.05
Beaver	47	1	1.5	1.5	3	0.5	0.5	1	4	4	22	0.01
Beaver	48	2	2	0.5	2.5	1.5	1.5	3	3	3	19.5	0.04
Beaver	49	2	2	1.5	3.5	0.5	1	1.5	3.5	3	21.5	0.01
Beaver	50	1.5	0	0.5	0.5	0.5	0	0.5	4	4	16.5	0.01
Beaver	51	1	2	1	3	1.5	0.5	1.5	2.5	3	19.5	0
Beaver	a	3	0.5	1.5	2	2	1	3	2.5	4	21.5	
Beaver	b	1	0	0	0	1	2	3	1.5	2	13.5	
Beaver	c	2	1.5	0	1.5	0	0.5	0.5	1.5	2	15.5	
Beaver	d	2	1.5	1	2.5	1.5	1.5	3	2.5	3	20.5	
Beaver	e	0	0	0	0	1	1.5	2.5	3.5	4	18	
Beaver	f	2	0.5	1	1.5	1.5	2	3.5	4	2	24	

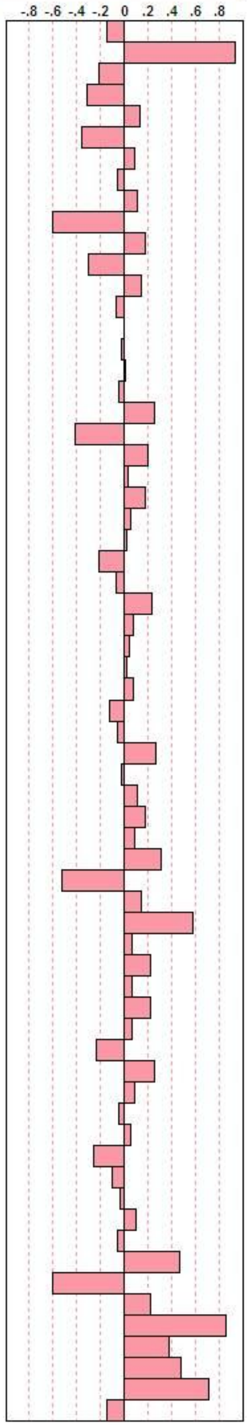
Stream	FID	Incision	Left Instability	Right Instability	Instability	Left Vegetation	Right Vegetation	Vegetation	Bank Accretion	SCE	RGA Score	Slope
Beaver	g	2	0	0	0	1	1.5	2.5	3.5	2	17	
Beaver	h	2	2	1	3	2	0.5	2.5	3	4	21.5	
Beaver	i	2	0.5	0	0.5	0	1	1	0.5	4	15	
Cox	52	2	1.5	1.5	3	1	0.5	1.5	2	3	20.5	1.28
Cox	53	3	0	0.5	0.5	1	0.5	1.5	1	3	15	0.17
Cox	54	2	1	0.5	1.5	0.5	0	0.5	3.5	3	16.5	0.25
Cox	55											0.78
North Fork	56	3	0	0	0	0.5	0.5	1	3.5	2	15.5	0.15
Mill	57	2	2	0.5	2.5	0.5	1.5	2	3.5	3	20	0.46
Haw	58	1	0	0	0	2	2	4	4	1	15	0.05
Haw	59	2	0.5	0.5	1	1.5	1	2.5	1	3	12.5	0.38
Haw	60	3	1	0	1	0	0	0	2	3	15	0.88
Kerns	61	1	0	1	1	2	1.5	3.5	1	3	13.5	1.75
Annon Trib	a	0	0.5	0.5	1	1	2	3	4	2	16	
Annon Trib	b	3	2	1.5	3.5	1.5	2	3.5	4	2	24	
Annon Trib	c	4	0	0	0	2	2	4	4	1.5	18.5	
Annon Trib	d	2	0	0	0	1	1.5	2.5	2	2	14.5	

Appendix C Pairwise Correlation Analysis of RGA Variables and Site Characteristics of Sites with Complete Evaluations

Multivariate

Pairwise Correlations

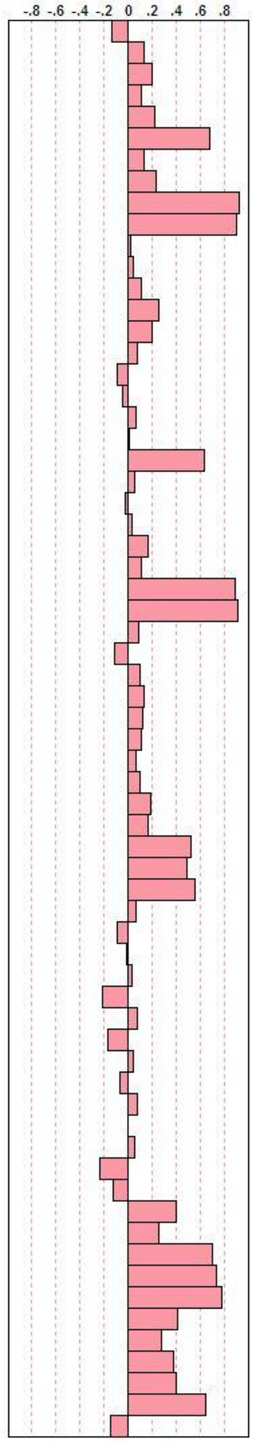
Variable	by Variable	Correlation	Count	Signif Prob
% Catchment Forrested	% Catch Developed	-0.1405	58	0.2928
% Impervious	% Catch Developed	0.9430	58	<.0001*
% Impervious	% Catchment Forrested	-0.2144	58	0.1061
Bed Material	% Catch Developed	-0.3086	57	0.0195*
Bed Material	% Catchment Forrested	0.1309	57	0.3317
Bed Material	% Impervious	-0.3608	57	0.0058*
D50	% Catch Developed	0.0879	53	0.5315
D50	% Catchment Forrested	-0.0557	53	0.6919
D50	% Impervious	0.1068	53	0.4464
D50	Bed Material	-0.6045	52	<.0001*
Incision	% Catch Developed	0.1838	57	0.1711
Incision	% Catchment Forrested	-0.2998	57	0.0235*
Incision	% Impervious	0.1431	57	0.2884
Incision	Bed Material	-0.0627	57	0.6432
Incision	D50	-0.0003	52	0.9981
Instability	% Catch Developed	-0.0251	57	0.8528
Instability	% Catchment Forrested	0.0154	57	0.9093
Instability	% Impervious	-0.0437	57	0.7467
Instability	Bed Material	0.2606	57	0.0502
Instability	D50	-0.4179	52	0.0020*
Instability	Incision	0.1990	57	0.1378
Vegetation	% Catch Developed	0.0348	57	0.7971
Vegetation	% Catchment Forrested	0.1800	57	0.1803
Vegetation	% Impervious	0.0578	57	0.6693
Vegetation	Bed Material	0.0260	57	0.8480
Vegetation	D50	-0.2107	52	0.1337
Vegetation	Incision	-0.0709	57	0.6001
Vegetation	Instability	0.2301	57	0.0851
Bank Accretion	% Catch Developed	0.0812	57	0.5484
Bank Accretion	% Catchment Forrested	0.0423	57	0.7545
Bank Accretion	% Impervious	0.0272	57	0.8410
Bank Accretion	Bed Material	0.0764	57	0.5720
Bank Accretion	D50	-0.1184	52	0.4032
Bank Accretion	Incision	-0.0603	57	0.6559
Bank Accretion	Instability	0.2685	57	0.0434*
Bank Accretion	Vegetation	-0.0179	57	0.8946
SCE Score	% Catch Developed	0.1138	57	0.3995
SCE Score	% Catchment Forrested	0.1806	57	0.1789
SCE Score	% Impervious	0.0887	57	0.5120
SCE Score	Bed Material	0.3172	57	0.0162*
SCE Score	D50	-0.5246	52	<.0001*
SCE Score	Incision	0.1422	57	0.2915
SCE Score	Instability	0.5855	57	<.0001*
SCE Score	Vegetation	0.0718	57	0.5956
SCE Score	Bank Accretion	0.2274	57	0.0890
Slope (ft/1000ft)	% Catch Developed	0.0701	62	0.5881
Slope (ft/1000ft)	% Catchment Forrested	0.2221	58	0.0938
Slope (ft/1000ft)	% Impervious	0.0696	58	0.6038
Slope (ft/1000ft)	Bed Material	-0.2334	57	0.0806
Slope (ft/1000ft)	D50	0.2590	53	0.0611
Slope (ft/1000ft)	Incision	0.0932	57	0.4903
Slope (ft/1000ft)	Instability	-0.0453	57	0.7382
Slope (ft/1000ft)	Vegetation	0.0539	57	0.6906
Slope (ft/1000ft)	Bank Accretion	-0.2542	57	0.0564
Slope (ft/1000ft)	SCE Score	-0.0975	57	0.4705
RGA Score	% Catch Developed	-0.0370	57	0.7848
RGA Score	% Catchment Forrested	0.1024	57	0.4486
RGA Score	% Impervious	-0.0607	57	0.6537
RGA Score	Bed Material	0.4690	57	0.0002*
RGA Score	D50	-0.6039	52	<.0001*
RGA Score	Incision	0.2195	57	0.1009
RGA Score	Instability	0.8553	57	<.0001*
RGA Score	Vegetation	0.3852	57	0.0031*
RGA Score	Bank Accretion	0.4770	57	0.0002*
RGA Score	SCE Score	0.7124	57	<.0001*
RGA Score	Slope (ft/1000ft)	-0.1472	57	0.2745



Appendix D Pairwise Correlation Analysis of RGA Variables and Site Characteristics of Sites with Complete Evaluations

Pairwise Correlations

Variable	by Variable	Correlation	Count	Signif Prob
Incision	Bed Material	-0.1385	91	0.1904
L Instability	Bed Material	0.1311	91	0.2156
L Instability	Incision	0.2031	91	0.0535
R Instability	Bed Material	0.1164	91	0.2719
R Instability	Incision	0.2255	91	0.0316*
R Instability	L Instability	0.6777	91	<.0001*
Instability	Bed Material	0.1354	91	0.2008
Instability	Incision	0.2336	91	0.0259*
Instability	L Instability	0.9220	91	<.0001*
Instability	R Instability	0.9096	91	<.0001*
Left Veg	Bed Material	0.0236	91	0.8246
Left Veg	Incision	0.0396	91	0.7095
Left Veg	L Instability	0.1152	91	0.2768
Left Veg	R Instability	0.2523	91	0.0158*
Left Veg	Instability	0.1980	91	0.0599
Right Veg	Bed Material	0.0828	91	0.4355
Right Veg	Incision	-0.0938	91	0.3763
Right Veg	L Instability	-0.0421	91	0.6920
Right Veg	R Instability	0.0642	91	0.5458
Right Veg	Instability	0.0100	91	0.9251
Right Veg	Left Veg	0.6372	91	<.0001*
Vegetation	Bed Material	0.0538	91	0.6127
Vegetation	Incision	-0.0267	91	0.8017
Vegetation	L Instability	0.0320	91	0.7632
Vegetation	R Instability	0.1712	91	0.1047
Vegetation	Instability	0.1082	91	0.3071
Vegetation	Left Veg	0.8951	91	<.0001*
Vegetation	Right Veg	0.9125	91	<.0001*
Bank Accretion	Bed Material	0.0928	91	0.3815
Bank Accretion	Incision	-0.1111	91	0.2945
Bank Accretion	L Instability	0.0979	91	0.3557
Bank Accretion	R Instability	0.1387	91	0.1898
Bank Accretion	Instability	0.1284	91	0.2252
Bank Accretion	Left Veg	0.1085	91	0.3059
Bank Accretion	Right Veg	0.0689	91	0.5162
Bank Accretion	Vegetation	0.0981	91	0.3548
SCE	Bed Material	0.1864	91	0.0769
SCE	Incision	0.1623	91	0.1242
SCE	L Instability	0.5225	91	<.0001*
SCE	R Instability	0.4910	91	<.0001*
SCE	Instability	0.5538	91	<.0001*
SCE	Left Veg	0.0683	91	0.5201
SCE	Right Veg	-0.0861	91	0.4172
SCE	Vegetation	-0.0128	91	0.9041
SCE	Bank Accretion	0.0286	91	0.7879
Slope	Bed Material	-0.2149	60	0.0992
Slope	Incision	0.0730	60	0.5796
Slope	L Instability	-0.1644	60	0.2095
Slope	R Instability	0.0478	60	0.7167
Slope	Instability	-0.0690	60	0.6003
Slope	Left Veg	0.0790	60	0.5484
Slope	Right Veg	0.0017	60	0.9898
Slope	Vegetation	0.0506	60	0.7009
Slope	Bank Accretion	-0.2350	60	0.0707
Slope	SCE	-0.1214	60	0.3555
RGA Score	Bed Material	0.4011	91	<.0001*
RGA Score	Incision	0.2607	91	0.0126*
RGA Score	L Instability	0.7020	91	<.0001*
RGA Score	R Instability	0.7376	91	<.0001*
RGA Score	Instability	0.7852	91	<.0001*
RGA Score	Left Veg	0.4167	91	<.0001*
RGA Score	Right Veg	0.2789	91	0.0074*
RGA Score	Vegetation	0.3802	91	0.0002*
RGA Score	Bank Accretion	0.4058	91	<.0001*
RGA Score	SCE	0.6496	91	<.0001*
RGA Score	Slope	-0.1472	60	0.2618



Appendix E The Modified Wolman Pebble Count Form

CHANNEL-STABILITY PARTICLE COUNT FORM

Station #__________________ **Station Description**______________________________

Date ____________ **Crew** ______________

Location/Description ____

(pool, riffle, 1 of 3, additional samples?)

1		**26**		**51**		**76**	
2		**27**		**52**		**77**	
3		**28**		**53**		**78**	
4		**29**		**54**		**79**	
5		**30**		**55**		**80**	
6		**31**		**56**		**81**	
7		**32**		**57**		**82**	
8		**33**		**58**		**83**	
9		**34**		**59**		**84**	
10		**35**		**60**		**85**	
11		**36**		**61**		**86**	
12		**37**		**62**		**87**	
13		**38**		**63**		**88**	
14		**39**		**64**		**89**	
15		**40**		**65**		**90**	
16		**41**		**66**		**91**	
17		**42**		**67**		**92**	
18		**43**		**68**		**93**	
19		**44**		**69**		**94**	
20		**45**		**70**		**95**	
21		**46**		**71**		**96**	
22		**47**		**72**		**97**	
23		**48**		**73**		**98**	
24		**49**		**74**		**99**	
25		**50**		**75**		**100**	

Appendix F Tabulated data for pebble counts at assessment sites

Stream	Mill	Kerns Branch	Cox	Cox	Cox	Cox	North Forl	Knob	Knob	Knob	Knob
Site											
Latitude	36.08865	36.14042	36.08538	36.07054	36.07903	36.07962	36.08155	36.02942	36.03187	36.03387	36.02567
Longitude	-83.9201	-83.8799	-83.8743	-83.9021	-83.8984	-83.8867	-83.9362	-83.9813	-83.9747	-83.9693	-83.9907
Particle Sixe (mm)	3	0.033	2	0.002	0.033	0.033	0.033	0.002	0.033	0.002	0.002
	4	0.033	3	0.002	1	0.033	0.033	0.002	0.033	1	0.002
	4	0.033	3	0.033	1	0.033	0.033	0.002	0.033	3	0.002
	4	0.033	4	0.033	1	0.033	0.033	0.002	0.033	4	0.002
	4	1	4	1	1	0.033	0.033	0.033	0.033	4	3
	4	1	4	1	3	0.033	0.033	1	2	4	3
	4	2	4	2	3	0.033	0.033	1	2	4	3
	4	2	5	2	4	0.033	0.033	1	3	4	3
	4	3	5	2	4	0.033	0.033	1	3	4	3
	4	4	5	2	5	0.033	0.033	3	3	4	4
	5	4	5	2	5	0.033	0.033	3	3	5	4
	5	5	6	2	5	0.033	0.033	4	3	5	5
	5	5	6	2	5	0.033	0.033	4	3	5	5
	5	5	6	2	5	0.033	0.033	4	4	5	5
	6	6	6	2	5	0.033	0.033	5	4	5	6
	6	6	6	2	5	0.033	0.033	5	4	6	7
	6	7	7	2	5	0.033	0.033	5	4	6	7
	6	7	7	3	6	0.033	0.033	6	4	6	8
	6	7	7	3	6	0.033	0.033	6	4	6	8
	6	7	7	3	6	0.033	0.033	6	4	7	8
	6	7	7	3	6	0.033	0.033	6	4	7	8
	6	7	7	3	7	0.033	0.033	7	4	7	9
	7	7	7	3	7	0.033	0.033	7	5	7	9
	7	8	7	3	7	0.033	0.033	7	5	7	9
	7	8	7	3	7	0.033	0.033	8	5	8	9
	7	8	7	3	7	0.033	0.033	8	5	8	9
	7	9	7	3	7	0.033	0.033	8	5	8	9
	7	9	7	3	7	0.033	0.033	9	5	9	9
	7	9	7	3	7	0.033	0.033	9	5	9	9
	7	9	7	3	7	0.033	0.033	9	5	9	9
	7	9	7	3	7	0.033	0.033	9	5	9	9
	7	10	7	3	8	0.033	0.033	9	5	9	9
	7	10	7	3	8	0.033	0.033	9	6	9	9
	7	10	7	4	8	0.033	0.033	9	6	9	9
	7	10	7	4	8	0.033	0.033	9	6	11	10
	7	10	7	4	8	0.033	0.033	9	6	11	10
	8	11	7	4	8	0.033	0.033	9	7	11	10
	8	11	7	4	8	0.033	0.033	9	7	11	11
	8	11	8	4	9	0.033	0.033	9	7	11	11
	8	11	8	4	9	0.033	0.033	10	7	11	11
	8	12	8	4	9	0.033	0.033	10	7	12	11
	8	13	8	4	9	0.033	0.033	10	7	12	11
	8	14	8	5	9	0.033	0.033	10	8	12	11
	8	15	8	5	9	0.033	0.033	10	8	14	12
	8	15	8	5	10	0.033	0.033	10	8	14	12
	8	15	8	5	10	0.033	0.033	10	8	15	12
	9	16	8	5	10	0.033	0.033	11	8	15	12
	9	16	8	5	10	0.033	0.033	11	8	15	12
	9	18	8	5	10	0.033	0.033	11	8	16	13
	9	18	8	5	10	0.033	0.033	11	9	16	14

Stream	Knob	Knob	Meadow	Meadow	Meadow	Meadow	Grassy	Grassy	Grassy	Grassy	Grassy
Site											
Latitude	36.02586	36.0221	35.9625	35.9639	35.96428	35.96527	35.97497	35.97822	35.98538	35.98728	35.98035
Longitude	-83.9955	-83.9961	-84.1093	-84.1285	-84.095	-84.119	-84.0743	-84.0645	-84.0592	-84.0596	-84.0603
Particle Sixe (mm)	0.033	0.002	1	0.033	0.033	3	1	0.033	1	0.033	0.033
	0.033	1	1	0.033	0.033	3	1	0.033	1	0.033	1
	0.033	2	1	0.033	0.033	3	2	1	1	0.033	1
	0.033	3	3	0.033	0.033	5	2	1	3	0.033	1
	0.033	4	3	0.033	0.033	5	3	1	3	0.033	2
	0.033	4	3	0.033	0.033	5	3	1	4	0.033	2
	0.033	5	3	0.033	0.033	5	3	1	4	0.033	3
	0.033	5	3	0.033	0.033	5	3	1	5	0.033	3
	0.033	5	4	0.033	0.033	5	4	1	5	0.033	3
	0.033	6	4	0.033	0.033	8	4	2	5	0.033	3
	0.033	6	4	0.033	1	8	4	2	5	0.033	3
	0.033	6	4	0.033	1	8	4	3	5	0.033	3
	0.033	7	4	1	1	8	4	3	5	0.033	3
	0.033	7	4	1	1	10	4	3	5	0.033	3
	0.033	7	4	1	1	10	4	3	5	0.033	3
	0.033	8	4	1	1	10	4	3	5	0.033	4
	0.033	9	4	2	2	10	5	3	5	0.033	4
	0.033	9	4	3	2	10	5	3	5	0.033	4
	0.033	9	5	3	2	10	5	4	5	0.033	4
	0.033	9	5	3	3	10	5	4	5	0.033	4
	0.033	9	5	4	4	10	5	4	5	0.033	4
	0.033	9	5	4	4	10	5	5	5	0.033	4
	0.033	9	5	5	4	10	6	5	5	0.033	4
	0.033	9	5	5	4	13	6	5	5	0.033	4
	0.033	9	5	5	5	13	6	5	6	0.033	4
	0.033	10	5	5	5	13	7	5	6	0.033	4
	0.033	10	5	5	5	13	7	5	6	0.033	4
	0.033	10	6	6	5	13	7	5	8	0.033	5
	0.033	10	6	6	5	13	7	5	8	0.033	5
	0.033	11	6	6	6	13	7	6	8	0.033	5
	0.033	11	6	6	6	13	7	6	8	0.033	5
	0.033	11	6	7	6	13	8	6	8	0.033	5
	0.033	11	6	7	6	13	8	6	8	0.033	5
	0.033	12	6	7	6	13	8	6	8	0.033	5
	0.033	12	6	8	6	13	8	6	8	0.033	5
	0.033	12	7	8	6	13	8	6	8	0.033	5
	0.033	12	7	8	6	15	8	7	8	0.033	5
	0.033	13	7	8	6	15	8	7	8	0.033	5
	0.033	14	7	8	7	15	8	7	8	0.033	5
	0.033	14	7	9	7	15	8	7	8	0.033	5
	0.033	14	7	9	7	15	9	7	8	0.033	6
	0.033	14	7	9	8	15	9	7	8	0.033	6
	0.033	14	7	9	8	15	9	7	9	0.033	6
	0.033	15	7	9	8	15	9	7	10	0.033	6
	0.033	15	8	9	8	15	9	7	10	0.033	6
	0.033	15	8	10	8	15	10	8	10	0.033	6
	0.033	15	8	11	8	18	10	8	10	0.033	6
	0.033	15	8	11	8	18	10	8	10	0.033	6
	0.033	15	8	11	8	18	11	9	10	0.033	6
	0.033	15	8	11	9	18	11	9	10	0.033	7

Stream	Grassy	Grassy	Grassy	Plumb	Plumb	Plumb	Plumb	Plumb	Hines	Hines	Hines
Site											
Latitude	35.99611	35.98701	35.9921	35.94647	35.95306	35.95834	35.9506	35.94952	36.05943	36.06877	36.06706
Longitude	-84.0386	-84.05	-84.0455	-84.1272	-84.1245	-84.1302	-84.1229	-84.1122	-83.9271	-83.9433	83.93056
Particle Sixe (mm)	1	3	1	0.033	0.002	1	0.002	1	0.002	0.002	1
	1	4	1	0.033	0.002	1	1	1	0.033	0.002	2
	3	4	1	0.033	0.033	1	1	1	0.033	0.002	2
	3	4	2	0.033	1	1	1	1	0.033	0.033	2
	4	4	2	3	1	1	1	1	0.033	0.033	2
	4	4	2	3	1	1	1	1	0.033	0.033	3
	4	4	2	3	1	3	1	1	0.033	0.033	3
	4	5	3	3	1	3	1	1	0.033	0.033	3
	5	5	3	3	1	3	1	1	0.033	0.033	3
	5	5	3	5	1	3	1	1	0.033	0.033	3
	5	5	3	5	1	3	1	1	0.033	0.033	3
	6	5	5	5	1	3	3	1	0.033	0.033	4
	6	5	5	5	3	3	3	3	0.033	1	4
	6	5	5	5	3	5	3	3	1	1	4
	7	5	5	5	3	5	3	3	1	1	4
	7	5	5	5	5	5	3	3	2	1	4
	8	5	6	5	5	5	3	3	3	1	4
	8	5	6	5	5	5	5	3	4	2	4
	8	5	7	5	5	5	5	3	4	2	4
	9	5	7	5	5	5	5	3	5	2	5
	9	6	7	5	5	5	5	3	5	3	5
	9	6	7	5	5	5	5	3	5	3	5
	9	6	7	5	5	8	5	5	5	3	5
	9	6	7	5	8	8	5	5	5	4	5
	9	6	7	8	8	8	5	5	5	4	5
	9	6	8	8	8	8	5	5	6	4	5
	9	7	8	8	8	8	5	5	6	4	6
	10	7	8	8	8	8	5	5	6	4	6
	10	8	8	8	8	8	5	5	6	4	6
	10	8	8	8	8	8	5	5	6	4	6
	10	8	9	8	8	8	5	5	7	4	7
	11	9	9	8	10	8	5	5	7	4	7
	11	9	9	8	10	8	5	5	7	5	8
	12	9	9	8	10	8	5	5	7	5	8
	12	9	9	8	10	10	5	5	7	5	9
	13	9	9	8	10	10	5	8	7	5	9
	13	9	9	8	10	10	5	8	8	5	9
	13	10	10	8	10	10	5	8	8	5	9
	13	10	10	8	10	10	8	8	8	5	10
	14	10	11	8	10	10	8	8	8	5	10
	14	10	11	8	10	10	8	8	8	5	10
	15	10	11	8	10	10	8	8	9	5	10
	15	10	11	10	10	13	8	8	9	5	11
	15	10	12	10	13	13	8	8	9	5	11
	15	11	12	10	13	13	8	8	9	6	12
	15	11	12	10	13	13	8	8	9	6	12
	15	11	12	10	13	13	8	8	10	6	12
	15	11	12	10	13	13	8	8	10	6	13
	16	12	13	10	13	13	8	8	10	6	13
	16	12	13	10	13	13	8	8	10	7	13

Stream	Hines	Hines	Willow	Willow	Willow	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver
Site											
Latitude	36.06593	36.06754	36.12764			36.082	36.04035	36.12419	36.10002	36.11416	35.97023
Longitude	-83.9265	-83.9291	-83.8913			-83.9244	-84.005	-83.8449	-83.8773	-83.8551	-83.1382
Particle Sixe (mm)	0.002	0.002	2	0.033	0.002	0.033	0.002	0.033	0.033	0.033	0.033
	0.002	0.002	3	0.033	0.002	0.033	0.002	0.033	0.033	0.033	0.033
	0.002	0.002	3	0.033	0.033	0.033	0.002	0.033	0.033	0.033	0.033
	1	0.002	3	0.033	0.033	0.033	0.002	0.033	0.033	0.033	0.033
	1	0.002	4	1	0.033	0.033	0.002	0.033	0.033	0.033	0.033
	1	1	4	1	0.033	0.033	0.002	0.033	0.033	0.033	0.033
	1	1	4	1	0.033	0.033	0.002	0.033	0.033	0.033	0.033
	1	2	4	1	0.033	0.033	0.002	0.033	0.033	0.033	0.033
	1	2	4	1	0.033	0.033	0.002	0.033	0.033	1	1
	1	3	4	2	0.033	1	0.002	0.033	0.033	1	1
	1	3	5	2	0.033	1	0.033	0.033	0.033	1	4
	1	3	5	2	0.033	1	0.033	0.033	0.033	1	4
	1	3	6	2	0.033	1	0.033	0.033	0.033	1	4
	1	3	6	2	0.033	1	0.033	0.033	0.033	1	4
	2	3	6	3	0.033	1	0.033	0.033	0.033	2	4
	2	4	6	3	0.033	1	0.033	0.033	0.033	3	4
	3	4	7	3	0.033	1	0.033	0.033	0.033	3	5
	3	4	7	3	1	1	0.033	0.033	0.033	3	5
	3	4	8	3	2	1	0.033	0.033	0.033	3	6
	3	5	8	3	2	1	0.033	0.033	0.033	3	6
	4	5	9	3	3	1	0.033	0.033	0.033	3	6
	4	5	9	3	3	1	0.033	0.033	0.033	4	6
	4	5	9	4	3	1	0.033	0.033	1	4	6
	4	5	10	4	4	1	0.033	0.033	2	5	6
	4	5	10	4	4	1	0.033	0.033	2	5	6
	4	6	10	4	4	1	0.033	0.033	3	5	7
	4	6	10	4	4	1	0.033	0.033	3	5	7
	4	6	11	5	4	1	0.033	0.033	3	5	8
	4	6	11	5	5	1	0.033	0.033	3	5	8
	4	6	12	5	5	2	0.033	0.033	4	5	8
	5	6	12	5	5	2	0.033	0.033	4	5	8
	5	6	13	5	5	2	0.033	0.033	4	5	8
	5	6	14	5	5	2	0.033	0.033	4	5	8
	6	7	15	5	5	3	0.033	0.033	4	6	9
	6	7	15	5	5	3	0.033	0.033	5	6	9
	6	7	15	6	5	3	0.033	0.033	5	6	9
	6	7	15	6	6	3	0.033	0.033	5	6	9
	6	7	16	6	6	3	0.033	0.033	5	6	9
	7	7	17	6	6	3	0.033	0.033	5	7	10
	7	8	18	6	6	3	0.033	0.033	5	7	10
	7	8	19	6	6	3	0.033	0.033	6	7	10
	7	8	19	6	7	3	0.033	0.033	6	7	10
	7	8	19	7	7	3	0.033	0.033	6	7	10
	8	8	19	7	7	3	0.033	0.033	6	8	10
	8	8	21	7	7	3	0.033	0.033	6	9	10
	8	9	21	7	7	3	0.033	0.033	6	9	11
	8	9	22	7	7	3	0.033	0.033	7	9	11
	9	9	22	7	7	4	0.033	0.033	7	10	11
	9	9	25	7	7	4	0.033	0.033	7	10	11
	9	9	26	7	7	4	0.033	0.033	7	10	11

Stream	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver
Site												
Latitude	35.98551	35.97441	35.96375	35.99747	36.11555	36.08078	36.03772	36.02633	36.07115	36.05851	36.01775	36.07982
Longitude	-84.1169	-84.1605	-84.1775	-84.0845	-83.8578	-83.9051	-84.0125	-84.0294	-83.9503	-83.9743	-84.0517	-83.9332
Particle Sixe (mm)	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	4	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	5	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	5	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	6	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	6	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	6	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	7	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	9	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	9	1	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	0.033	10	1	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	1	11	1	0.033	0.033	0.033	0.033	0.033	0.033	0.002	0.033	0.002
	4	11	1	0.033	1	0.033	0.033	0.033	1	0.002	0.033	0.002
	4	12	1	0.033	1	0.033	0.033	0.033	1	0.002	0.033	0.002
	5	13	1	0.033	1	0.033	0.033	0.033	1	0.002	0.033	0.002
	6	14	2	0.033	1	0.033	0.033	0.033	1	0.002	0.033	0.002
	6	16	3	0.033	1	0.033	0.033	0.033	1	0.002	0.033	0.002
	6	17	3	0.033	1	0.033	0.033	0.033	1	0.002	0.033	0.002
	8	24	4	0.033	3	0.033	0.033	0.033	1	0.002	0.033	0.002
	9	24	4	0.033	4	0.033	0.033	0.033	1	0.033	0.033	0.033
	9	26	4	0.033	4	0.033	0.033	0.033	1	0.033	0.033	0.033
	10	29	4	0.033	4	0.033	0.033	0.033	1	0.033	0.033	0.033
	10	34	6	0.033	5	0.033	0.033	0.033	1	0.033	0.033	0.033
	12	34	7	0.033	6	0.033	0.033	0.033	1	0.033	0.033	0.033
	14	38	7	0.033	6	1	0.033	0.033	1	0.033	0.033	0.033
	14	38	7	0.033	6	1	0.033	0.033	1	0.033	1	0.033
	15	40	7	0.033	6	1	0.033	0.033	1	0.033	1	0.033
	15	40	8	0.033	6	1	0.033	0.033	1	0.033	1	0.033
	16	46	8	0.033	7	1	0.033	0.033	2	0.033	1	0.033
	16	47	8	0.033	7	1	0.033	0.033	3	0.033	1	0.033
	17	48	8	0.033	7	1	0.033	0.033	3	0.033	1	0.033
	18	48	9	0.033	8	1	0.033	0.033	3	0.033	1	0.033
	19	51	9	0.033	8	1	0.033	0.033	3	0.033	1	0.033
	19	52	10	0.033	9	2	0.033	0.033	3	0.033	1	0.033
	20	54	10	0.033	9	2	0.033	0.033	3	0.033	3	0.033
	20	56	11	0.033	10	2	0.033	0.033	3	0.033	3	0.033
	20	57	11	0.033	10	2	0.033	0.033	4	0.033	3	0.033
	20	58	11	0.033	10	2	0.033	0.033	4	0.033	4	0.033
	20	59	12	0.033	11	2	0.033	0.033	4	0.033	4	0.033
	20	61	12	0.033	12	3	0.033	0.033	4	0.033	4	0.033
	21	65	13	0.033	13	3	0.033	0.033	4	0.033	5	0.033
	21	67	14	0.033	14	3	0.033	0.033	4	0.033	5	0.033
	22	68	14	0.033	14	3	0.033	0.033	4	0.033	5	0.033
	22	73	16	0.033	16	3	0.033	0.033	4	0.033	5	0.033
	22	74	16	0.033	20	3	0.033	0.033	4	0.033	5	0.033
	24	75	17	0.033	21	3	0.033	0.033	4	0.033	5	0.033
	24	77	17	0.033	24	3	0.033	0.033	4	0.033	6	0.033
	24	77	17	0.033	27	3	0.033	0.033	5	0.033	6	0.033

Stream	Mill	Kerns Branch	Cox	Cox	Cox	Cox	North Forl	Knob	Knob	Knob	Knob
Site											
Latitude	36.08865	36.14042	36.08538	36.07054	36.07903	36.07962	36.08155	36.02942	36.03187	36.03387	36.02567
Longitude	-83.9201	-83.8799	-83.8743	-83.9021	-83.8984	-83.8867	-83.9362	-83.9813	-83.9747	-83.9693	-83.9907
	9	21	9	5	11	0.033	0.033	12	9	16	14
	9	21	9	5	11	0.033	0.033	12	9	17	14
	9	23	9	5	11	0.033	0.033	12	9	18	14
	9	24	9	6	11	0.033	0.033	12	9	18	14
	9	24	9	6	11	0.033	0.033	12	9	18	15
	9	27	9	6	11	0.033	0.033	12	9	19	15
	9	28	9	6	11	0.033	0.033	13	9	19	16
	9	29	9	6	12	0.033	0.033	13	9	20	16
	9	31	9	6	12	0.033	0.033	13	9	20	17
	9	32	9	7	12	0.033	0.033	13	9	20	18
	10	34	9	7	13	0.033	0.033	14	9	22	18
	10	35	9	7	13	0.033	0.033	14	9	23	18
	10	35	9	7	13	0.033	0.033	14	9	26	19
	10	36	9	7	14	0.033	0.033	14	9	27	19
	10	46	9	7	14	0.033	0.033	15	9	29	19
	10	47	10	7	15	0.033	0.033	15	10	29	19
	10	49	10	7	15	0.033	0.033	15	10	29	20
	10	49	10	8	15	0.033	0.033	15	10	30	20
	11	49	10	8	15	0.033	0.033	15	10	32	20
	11	50	10	8	16	0.033	0.033	16	11	32	20
	11	51	10	8	16	0.033	0.033	16	11	32	20
	12	54	10	8	17	0.033	0.033	16	12	34	20
	12	55	10	8	17	0.033	0.033	17	13	35	22
	12	57	10	8	18	0.033	0.033	17	13	37	22
	13	57	11	9	19	0.033	0.033	18	14	42	23
	14	61	11	9	20	0.033	0.033	18	14	43	23
	14	67	11	9	20	0.033	0.033	18	14	43	23
	14	72	11	9	21	0.033	0.033	18	14	45	24
	15	74	12	9	21	0.033	0.033	18	14	49	24
	16	74	13	9	21	1	0.033	18	15	53	24
	17	74	13	9	23	1	0.033	19	15	56	24
	17	76	14	9	23	1	0.033	19	15	59	24
	18	78	15	10	26	1	0.033	20	16	60	24
	18	80	15	10	27	1	0.033	20	16	63	25
	19	81	15	10	27	1	1	20	16	68	25
	19	91	15	10	28	1	1	20	18	68	26
	19	97	16	10	31	1	1	22	19	79	26
	19	109	16	11	33	1	1	22	19	81	29
	20	111	16	11	38	1	1	24	19	84	31
	21	111	16	12	38	1	1	25	23	87	31
	21	112	17	12	57	1	1	25	47	105	33
	24	112	17	14	61	1	1	25	47	500	35
	24	113	18	15	66	1	1	28	174	500	35
	24	120	18	15	66	1	1	30	500	500	35
	25	121	20	16	96		1	32	500	500	40
	27	124	20	16	500		1	37	500	500	41
	32	192	23	16	500		1	44	500	500	45
	34	192	23	17	500		1	45	500	500	46
	39	500	38	17	500		1	82	500	500	53
Mean	10.92	42.34132	9.71	6.1007	34.18033	0.185684	0.17805	13.44041	40.12165	61.13002	16.02008
Median	9	19	8	5	10	0.033	0.033	11.5	9	16	14
d16	6	6	6	2	5	0.033	0.033	5	4	6	7
d50	9	18	8	5	10	0.033	0.033	11	9	16	14
d84	18	78	15	10	26	0.033	0.033	20	16	60	24

Stream	Knob	Knob	Meadow	Meadow	Meadow	Meadow	Grassy	Grassy	Grassy	Grassy	Grassy
Site											
Latitude	36.02586	36.0221	35.9625	35.9639	35.96428	35.96527	35.97497	35.97822	35.98538	35.98728	35.98035
Longitude	-83.9955	-83.9961	-84.1093	-84.1285	-84.095	-84.119	-84.0743	-84.0645	-84.0592	-84.0596	-84.0603
	11	0.033	16	8	12	9	18	11	9	10	0.033
	11	0.033	16	9	12	9	20	11	9	10	0.033
	12	0.033	16	9	12	9	20	12	10	10	0.033
	12	0.033	16	9	12	9	20	12	10	10	0.033
	12	0.033	16	9	13	9	20	12	10	10	0.033
	12	0.033	17	9	13	9	20	12	10	10	0.033
	13	0.033	17	9	13	9	20	12	11	10	0.033
	13	0.033	17	9	14	10	20	12	11	10	0.033
	14	0.033	17	9	14	10	23	13	11	10	0.033
	14	0.033	18	9	14	10	23	14	12	10	0.033
	14	0.033	18	9	14	10	23	14	12	13	0.033
	15	0.033	18	10	14	10	23	14	12	13	0.033
	15	0.033	18	10	15	10	23	14	12	13	0.033
	15	0.033	18	10	15	10	23	14	12	13	0.033
	16	0.033	19	10	15	10	25	14	12	13	0.033
	16	0.033	19	10	16	11	25	15	12	13	0.033
	16	0.033	19	10	17	11	25	15	13	13	0.033
	16	0.033	19	10	17	12	25	15	13	13	0.033
	16	0.033	20	10	17	12	25	16	13	13	0.033
	17	0.033	20	11	17	12	25	16	13	14	0.033
	17	0.033	20	11	18	13	25	17	14	15	0.033
	17	0.033	20	11	18	14	28	17	14	15	0.033
	18	0.033	20	12	18	14	28	17	14	15	0.033
	18	0.033	21	12	18	15	28	18	14	15	0.033
	19	0.033	21	12	19	15	28	18	14	15	0.033
	19	0.033	22	13	19	15	30	18	15	15	0.033
	19	0.033	22	13	19	16	30	19	15	15	0.033
	19	0.033	23	14	20	17	30	19	15	15	0.033
	19	0.033	23	14	20	17	30	19	16	15	0.033
	20	0.033	24	14	21	17	30	20	16	15	0.033
	20	0.033	25	15	21	18	30	20	18	15	0.033
	20	0.033	25	15	22	21	30	20	18	15	0.033
	22	0.033	25	15	22	21	33	20	18	18	0.033
	22	0.033	26	15	22	21	33	23	18	18	0.033
	22	0.033	26	16	23	22	33	24	19	18	0.033
	23	0.033	26	16	24	22	36	25	19	18	0.033
	24	0.033	27	16	24	23	36	26	19	20	0.033
	24	0.033	29	17	25	23	38	27	20	20	0.033
	27	0.033	29	17	25	24	41	27	20	20	0.033
	31	0.033	31	18	25	26	41	28	21	23	0.033
	32	0.033	31	19	26	26	41	28	22	23	0.033
	33	0.033	33	19	26	30	41	29	22	23	0.033
	33	0.033	39	19	27	32	43	30	24	25	0.033
	34	0.033	39	21	27	35	43	32	24	25	0.033
	35	0.033	42	22	27	39	48	33	24	28	0.033
	36	0.033	48	25	29	49	58	47	27	28	0.033
	40	0.033	65	27	35	50	66	52	30	30	0.033
	42	0.033	66	27	38	52	79	74	32	36	0.033
	53	0.033	75	34	48		192		36	53	0.033
Mean	13.30231	0.033	17.70002	9.58	12.45396	11.12455	22.75	13.48485	10.45066	11.66	0.033
Median	11	0.033	15.5	8	11.5	9	18	11	9	10	0.033
d16	3	0.033	8	4	1	1	10	4	3	5	0.033
d50	11	0.033	15	8	11	9	18	11	9	10	0.033
d84	22	0.033	25	15	22	21	33	20	18	18	0.033

Stream	Grassy	Grassy	Grassy	Plumb	Plumb	Plumb	Plumb	Plumb	Hines	Hines	Hines
Site											
Latitude	35.99611	35.98701	35.9921	35.94647	35.95306	35.95834	35.9506	35.94952	36.05943	36.06877	36.06706
Longitude	-84.0386	-84.05	-84.0455	-84.1272	-84.1245	-84.1302	-84.1229	-84.1122	-83.9271	-83.9433	83.93056
	16	12	13	10	13	13	8	8	11	7	14
	16	12	14	10	13	13	8	8	11	7	14
	16	12	14	10	13	15	8	8	12	7	14
	17	12	14	10	13	15	8	8	16	7	14
	17	12	14	10	13	15	8	8	16	7	15
	18	12	14	10	13	15	10	8	18	7	15
	18	12	14	10	13	15	10	10	18	7	16
	18	12	15	10	15	15	10	10	18	7	16
	18	12	15	10	15	15	10	10	19	7	17
	18	13	15	10	15	15	10	10	22	7	17
	19	13	15	13	18	15	10	10	27	8	17
	19	13	15	13	20	18	10	10	29	8	17
	21	13	15	13	20	18	10	10	31	8	17
	21	13	15	13	23	18	10	10	31	9	17
	22	13	16	13	23	18	10	10	32	9	19
	22	14	16	13	23	18	10	10	34	9	19
	23	14	17	13	23	18	10	10	34	9	19
	23	15	17	13	25	18	13	13	40	9	20
	24	15	17	13	25	18	13	13	43	9	20
	24	16	18	13	25	18	13	13	44	10	20
	25	17	18	13	28	20	13	13	46	10	21
	25	17	19	13	28	20	13	13	77	10	22
	25	18	19	15	28	20	13	13	97	11	22
	25	18	19	15	33	20	13	13	106	11	25
	25	19	19	15	36	20	13	13	109	11	25
	27	19	20	15	41	20	15	15	112	11	28
	28	19	20	15	43	23	15	15	118	11	32
	29	19	21	15	43	23	15	15	121	12	33
	31	19	21	15	46	23	15	15	192	12	33
	33	20	21	15	46	25	15	15		12	34
	33	21	21	15	48	25	15	15		12	34
	34	21	23	15	48	28	15	18		13	35
	35	25	23	18	51	30	15	18		14	36
	35	25	24	18	51	33	15	18		14	43
	37	25	24	18	53	33	18	20		15	51
	38	25	25	18	53	36	18	20		16	53
	40	27	26	20	56	38	18	23		16	65
	41	29	27	20	58	38	18	25		16	67
	42	30	28	23	64	41	18	28		16	70
	44	32	28	23	69	41	18	30		17	85
	44	34	30	25	74	41	20	38		18	93
	44	35	30	25	76	41	20	53		18	109
	44	42	31	28	117	41	23	58		20	110
	46	44	36	30	500	43	25	500		22	111
	52	51	41	30	500	46	25	500		24	115
	53	55	44	33	500	56	25	500		26	121
	61	61	59	38	500	56	25	500		27	500
	79	86	84	43	500	56	30	500		27	500
	500	500	85	500	500	61	33	500		35	500
Mean	24.51	19.83	15.64	16.40132	48.97037	16.86	9.70002	39.36	21.71748	7.95303	36.44
Median	16	12	13	10	13	13	8	8	8	7	13
d16	7	5	5	5	5	5	3	3	0.033	1	4
d50	16	12	13	10	13	13	8	8	8	7	13
d84	35	25	23	18	51	30	15	18	34	14	36

Stream	Hines	Hines	Willow	Willow	Willow	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver
Site											
Latitude	36.06593	36.06754	36.12764			36.082	36.04035	36.12419	36.10002	36.11416	35.97023
Longitude	-83.9265	-83.9291	-83.8913			-83.9244	-84.005	-83.8449	-83.8773	-83.8551	-83.1382
	10	10	31	8	7	4	0.033	0.033	7	10	12
	10	10	33	8	8	4	0.033	0.033	7	11	12
	10	10	35	9	8	4	0.033	0.033	7	11	13
	10	10	38	9	9	4	0.033	0.033	7	12	13
	11	10	42	9	9	4	0.033	0.033	8	12	13
	11	10	42	9	9	4	0.033	0.033	8	13	14
	11	10	42	9	9	4	0.033	0.033	8	13	14
	11	11	43	9	9	5	0.033	0.033	9	13	14
	11	11	46	9	9	5	0.033	0.033	9	14	14
	11	12	46	9	9	5	0.033	0.033	9	14	15
	11	12	46	10	9	5	0.033	0.033	9	14	15
	11	12	47	10	9	5	0.033	0.033	9	15	15
	12	12	47	10	9	5	0.033	0.033	9	15	15
	12	12	54	10	9	5	0.033	0.033	10	16	15
	12	13	62	10	9	5	0.033	0.033	10	16	15
	14	13	64	11	9	5	0.033	0.033	10	19	15
	14	14	64	11	10	5	0.033	0.033	10	19	16
	14	15	66	11	10	6	0.033	0.033	11	19	17
	15	15	68	12	10	6	0.033	0.033	11	20	18
	15	16	69	12	11	6	0.033	0.033	11	25	18
	17	16	72	12	11	7	0.033	0.033	11	29	18
	18	16	78	12	11	8	0.033	0.033	11	30	18
	18	16	82	13	11	192	0.033	0.033	12	42	19
	18	16	83	13	12	192	0.033	0.033	12	42	19
	18	17	86	13	12	192	0.033	0.033	12	45	20
	19	18	87	13	12	192	0.033	0.033	12	46	20
	20	19	97	14	13	192	0.033	0.033	12	64	20
	21	19	98	14	13	192	0.033	0.033	12	65	20
	21	20	98	14	13	192	0.033	0.033	12	75	20
	22	21	100	14	14	192	0.033	1	12	76	20
	23	22	106	14	14	192	0.033	1	13	80	21
	23	24	114	15	15	192	0.033	1	13	81	21
	23	25	115	15	15	192	0.033	1	14	85	21
	23	28	120	15	15	192	0.033	1	14	85	21
	28	30	121	15	15	192	0.033	1	14	88	22
	30	32	126	16	17	192	0.033	1	15	90	22
	32	32	500	17	18	192	0.033	1	15	92	22
	36	33	500	17	19	192	0.033	1	15	94	22
	38	36	500	17	20	192	0.033	1	15	110	24
	43	38	500	17	21	192	0.033	1	16	112	27
	46	38	500	17	21	192	0.033	1	16	116	29
	47	38	500	17	21	192	0.033	1	18	121	30
	64	40	500	18	22	192	0.033	1	18	192	30
	69	41	500	18	22	192	0.033	1	19	500	31
	83	46	500	18	23	192	1	1	22	500	34
	114	61	500	21	24	192	1	1	36	500	40
	500	76	500	25	25	192	1	1	47	500	46
	500	119	500	25	28	192	1	1	192	500	49
	500	500	500	25	28	192	1	1	192	500	50
Mean	28.65006	19.3801	96.61	8.74132	8.60499	53.81297	0.07825	0.2264	11.39726	53.85264	13.71264
Median	9	9.5	28	7.5	7	4	0.033	0.033	7	10	11.5
d16	2	4	6	3	0.033	1	0.033	0.033	0.033	3	4
d50	9	9	26	7	7	4	0.033	0.033	7	10	11
d84	23	25	115	15	15	192	0.033	1	14	85	21

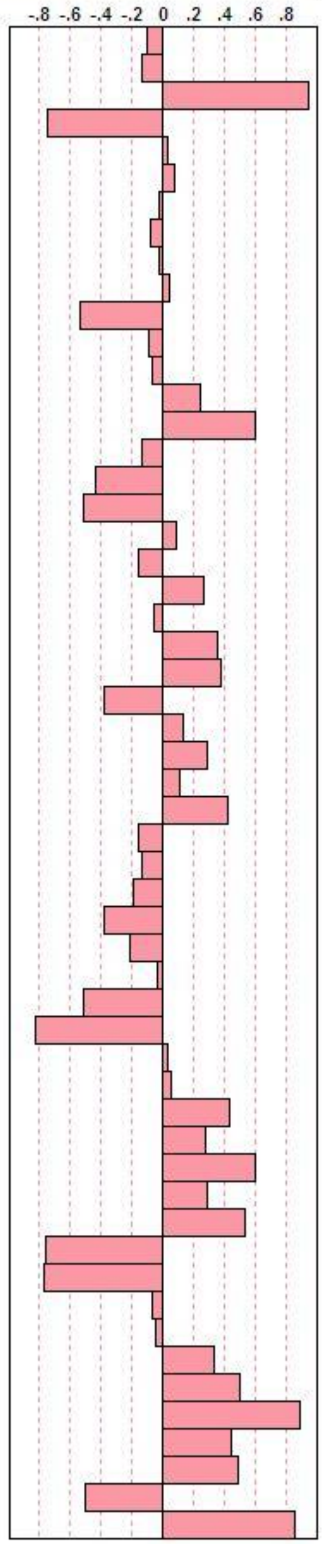
Stream	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver	Beaver
Site												
Latitude	35.98551	35.97441	35.96375	35.99747	36.11555	36.08078	36.03772	36.02633	36.07115	36.05851	36.01775	36.07982
Longitude	-84.1169	-84.1605	-84.1775	-84.0845	-83.8578	-83.9051	-84.0125	-84.0294	-83.9503	-83.9743	-84.0517	-83.9332
	25	79	24	0.033	35	4	0.033	0.033	5	0.033	6	0.033
	25	80	24	0.033	35	4	0.033	0.033	5	0.033	6	0.033
	25	81	27	0.033	35	4	0.033	0.033	6	0.033	6	0.033
	26	81	31	0.033	36	4	0.033	0.033	6	0.033	6	0.033
	26	84	32	0.033	38	4	0.033	0.033	6	0.033	6	0.033
	26	85	32	0.033	38	4	0.033	0.033	6	0.033	6	0.033
	27	88	32	0.033	47	4	0.033	0.033	6	0.033	7	0.033
	27	89	34	0.033	54	4	0.033	0.033	6	0.033	7	0.033
	28	89	36	0.033	55	4	0.033	0.033	6	0.033	7	0.033
	28	92	36	0.033	68	4	0.033	0.033	6	0.033	7	0.033
	30	94	37	0.033	69	4	0.033	0.033	6	0.033	7	0.033
	30	94	38	0.033	69	5	0.033	0.033	7	0.033	8	0.033
	30	95	42	0.033	74	5	0.033	0.033	7	0.033	8	0.033
	30	95	43	0.033	79	5	0.033	0.033	7	0.033	8	0.033
	30	95	43	0.033	80	5	0.033	0.033	7	0.033	8	0.033
	30	98	47	0.033	84	6	0.033	0.033	8	0.033	8	0.033
	30	101	48	0.033	84	6	0.033	0.033	8	0.033	9	0.033
	30	102	48	0.033	88	6	0.033	0.033	8	0.033	9	0.033
	30	105	49	0.033	88	6	0.033	0.033	8	0.033	10	0.033
	31	109	50	0.033	91	6	0.033	0.033	8	0.033	10	0.033
	31	110	50	0.033	94	6	0.033	0.033	8	0.033	10	0.033
	33	111	52	0.033	97	6	0.033	0.033	9	0.033	10	0.033
	33	112	59	0.033	99	6	0.033	0.033	9	0.033	10	0.033
	34	117	59	0.033	99	7	0.033	0.033	9	0.033	10	0.033
	34	119	65	0.033	106	7	0.033	0.033	9	0.033	10	0.033
	34	121	68	0.033	109	8	0.033	0.033	10	0.033	10	0.033
	35	130	71	0.033	111	8	0.033	0.033	10	0.033	10	0.033
	38	131	76	0.033	113	8	0.033	0.033	10	0.033	10	0.033
	39	133	78	0.033	115	8	0.033	0.033	10	0.033	10	0.033
	39	146	89	0.033	120	9	0.033	0.033	10	0.033	10	0.033
	40	179	89	0.033	124	9	0.033	0.033	10	0.033	11	0.033
	40	186	91	0.033	126	10	0.033	0.033	10	0.033	11	0.033
	40		99	0.033	192	10	0.033	0.033	10	0.033	11	0.033
	40		103	0.033	192	10	0.033	0.033	11	0.033	12	0.033
	41		120	0.033	192	11	0.033	0.033	11	0.033	12	0.033
	42		158	0.033	192	13	0.033	0.033	12	0.033	12	0.033
	43		205	0.033	500	13	0.033	0.033	12	0.033	12	0.033
	44			0.033	500	13	0.033	0.033	12	0.033	13	0.033
	45			0.033	500	13	0.033	0.033	12	0.033	14	0.033
	45			0.033	500	14	0.033	0.033	12	0.033	14	0.033
	46			0.033	500	16	0.033	0.033	13	0.033	14	0.033
	52			0.033	500	16	0.033	0.033	13	0.033	15	0.033
	60			0.033	500	18	0.033	0.033	14	0.033	15	0.033
	61			0.033	500	18	0.033	0.033	15	0.033	17	0.033
	61			1	500	18	10	0.033	16	1	18	0.033
	62			1	500	21	10	0.033	16	1	19	0.033
	65			1	500	22	10	0.033	20	1	20	0.033
	66			1	500	24	10	0.033	20	1	24	0.033
				1		31	10	0.033	28	1	35	0.033
Mean	24.09524	62.77228	29.76549	0.08135	97.68143	5.19858	0.53135	0.033	5.86462	0.07484	6.26891	0.02649
Median	24	61	14	0.033	27	3.5	0.033	0.033	5	0.033	6	0.033
d16	4	10	1	0.033	1	0.033	0.033	0.033	1	0.002	0.033	0.002
d50	24	61	14	0.033	27	3	0.033	0.033	5	0.033	6	0.033
d84	40	105	59	0.033	126	10	0.033	0.033	10	0.033	11	0.033

Appendix G Pairwise Correlations of Variables in Watersheds of Similar Levels of Development

Low Development Watersheds

Pairwise Correlations

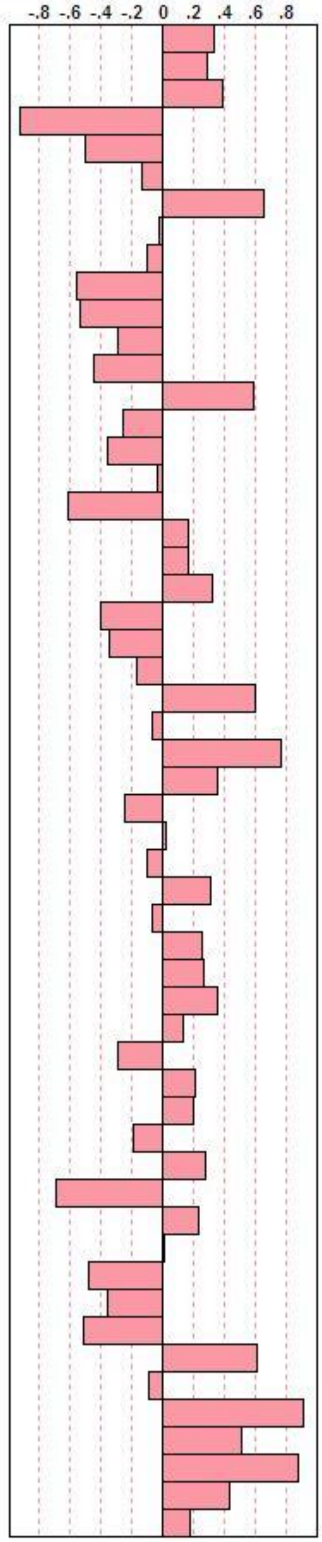
Variable	by Variable	Correlation	Count	Signif Prob
% Catch Developed	D50	-0.1044	10	0.7742
% Local Developed	D50	-0.1354	10	0.7092
% Local Developed	% Catch Developed	0.9542	12	<.0001*
Bed Material	D50	-0.7475	9	0.0206*
Bed Material	% Catch Developed	0.0294	11	0.9316
Bed Material	% Local Developed	0.0802	11	0.8146
Incision	D50	-0.0265	9	0.9461
Incision	% Catch Developed	-0.0829	11	0.8085
Incision	% Local Developed	-0.0275	11	0.9361
Incision	Bed Material	0.0481	11	0.8882
Instability	D50	-0.5400	9	0.1334
Instability	% Catch Developed	-0.0905	11	0.7913
Instability	% Local Developed	-0.0627	11	0.8547
Instability	Bed Material	0.2510	11	0.4567
Instability	Incision	0.5991	11	0.0514
Vegetation	D50	-0.1322	9	0.7345
Vegetation	% Catch Developed	-0.4335	11	0.1829
Vegetation	% Local Developed	-0.5180	11	0.1026
Vegetation	Bed Material	0.0903	11	0.7918
Vegetation	Incision	-0.1532	11	0.6529
Vegetation	Instability	0.2698	11	0.4223
Bank Accretion	D50	-0.0552	9	0.8878
Bank Accretion	% Catch Developed	0.3575	11	0.2805
Bank Accretion	% Local Developed	0.3831	11	0.2449
Bank Accretion	Bed Material	-0.3852	11	0.2420
Bank Accretion	Incision	0.1298	11	0.7036
Bank Accretion	Instability	0.2927	11	0.3825
Bank Accretion	Vegetation	0.1082	11	0.7516
Slope	D50	0.4290	10	0.2161
Slope	% Catch Developed	-0.1590	12	0.6217
Slope	% Local Developed	-0.1290	12	0.6895
Slope	Bed Material	-0.1863	11	0.5834
Slope	Incision	-0.3813	11	0.2472
Slope	Instability	-0.2159	11	0.5238
Slope	Vegetation	-0.0378	11	0.9122
Slope	Bank Accretion	-0.5102	11	0.1088
SCE	D50	-0.8292	9	0.0057*
SCE	% Catch Developed	0.0361	11	0.9162
SCE	% Local Developed	0.0609	11	0.8588
SCE	Bed Material	0.4318	11	0.1847
SCE	Incision	0.2792	11	0.4057
SCE	Instability	0.6028	11	0.0496*
SCE	Vegetation	0.2886	11	0.3894
SCE	Bank Accretion	0.5324	11	0.0918
SCE	Slope	-0.7580	11	0.0069*
RGA Score	D50	-0.7685	9	0.0155*
RGA Score	% Catch Developed	-0.0631	11	0.8537
RGA Score	% Local Developed	-0.0455	11	0.8943
RGA Score	Bed Material	0.3301	11	0.3214
RGA Score	Incision	0.4978	11	0.1192
RGA Score	Instability	0.8965	11	0.0002*
RGA Score	Vegetation	0.4485	11	0.1665
RGA Score	Bank Accretion	0.4915	11	0.1247
RGA Score	Slope	-0.5061	11	0.1122
RGA Score	SCE	0.8583	11	0.0007*



Medium Development Watersheds

Pairwise Correlations

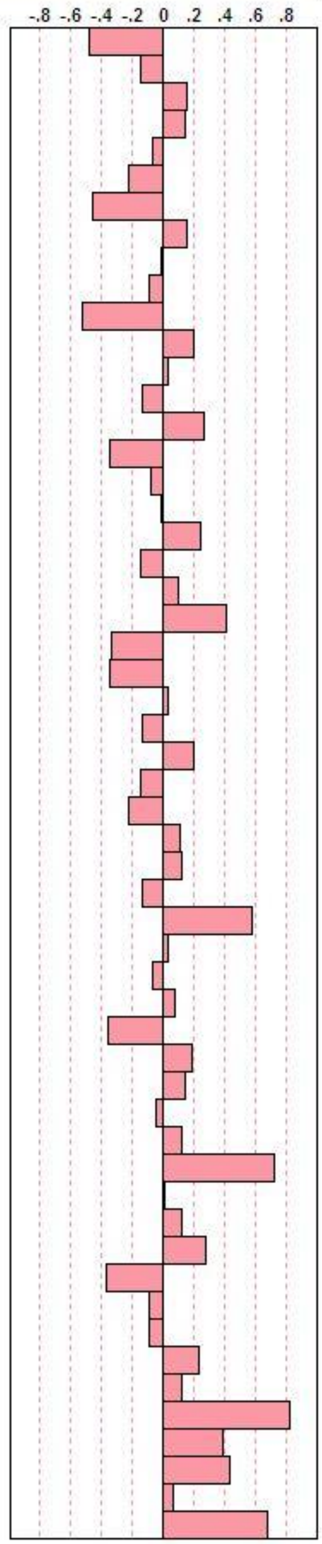
Variable	by Variable	Correlation	Count	Signif Prob
% Catch Developed	D50	0.3405	11	0.3056
% Local Developed	D50	0.2913	11	0.3848
% Local Developed	% Catch Developed	0.3963	12	0.2021
Bed Material	D50	-0.9315	11	<.0001*
Bed Material	% Catch Developed	-0.4987	12	0.0988
Bed Material	% Local Developed	-0.1386	12	0.6675
Incision	D50	0.6539	11	0.0291*
Incision	% Catch Developed	-0.0171	12	0.9578
Incision	% Local Developed	-0.0955	12	0.7677
Incision	Bed Material	-0.5557	12	0.0607
Instability	D50	-0.5332	11	0.0912
Instability	% Catch Developed	-0.2874	12	0.3650
Instability	% Local Developed	-0.4499	12	0.1422
Instability	Bed Material	0.5897	12	0.0436*
Instability	Incision	-0.2554	12	0.4229
Vegetation	D50	-0.3593	11	0.2779
Vegetation	% Catch Developed	-0.0340	12	0.9163
Vegetation	% Local Developed	-0.6142	12	0.0336*
Vegetation	Bed Material	0.1649	12	0.6084
Vegetation	Incision	0.1731	12	0.5905
Vegetation	Instability	0.3232	12	0.3055
Bank Accretion	D50	-0.4052	11	0.2163
Bank Accretion	% Catch Developed	-0.3462	12	0.2703
Bank Accretion	% Local Developed	-0.1691	12	0.5993
Bank Accretion	Bed Material	0.6069	12	0.0364*
Bank Accretion	Incision	-0.0683	12	0.8331
Bank Accretion	Instability	0.7698	12	0.0034*
Bank Accretion	Vegetation	0.3545	12	0.2582
Slope	D50	-0.2452	11	0.4675
Slope	% Catch Developed	0.0279	12	0.9314
Slope	% Local Developed	-0.0968	13	0.7532
Slope	Bed Material	0.3099	12	0.3270
Slope	Incision	-0.0722	12	0.8236
Slope	Instability	0.2596	12	0.4151
Slope	Vegetation	0.2646	12	0.4060
Slope	Bank Accretion	0.3552	12	0.2572
SCE	D50	0.1386	11	0.6844
SCE	% Catch Developed	-0.2940	12	0.3537
SCE	% Local Developed	0.2159	12	0.5003
SCE	Bed Material	0.2058	12	0.5211
SCE	Incision	-0.1852	12	0.5645
SCE	Instability	0.2802	12	0.3778
SCE	Vegetation	-0.6893	12	0.0131*
SCE	Bank Accretion	0.2359	12	0.4604
SCE	Slope	0.0109	12	0.9732
RGA Score	D50	-0.4756	11	0.1392
RGA Score	% Catch Developed	-0.3523	12	0.2615
RGA Score	% Local Developed	-0.5122	12	0.0887
RGA Score	Bed Material	0.6199	12	0.0315*
RGA Score	Incision	-0.0938	12	0.7718
RGA Score	Instability	0.9142	12	<.0001*
RGA Score	Vegetation	0.5158	12	0.0861
RGA Score	Bank Accretion	0.8866	12	0.0001*
RGA Score	Slope	0.4388	12	0.1535
RGA Score	SCE	0.1790	12	0.5777



High Development Watersheds

Pairwise Correlations

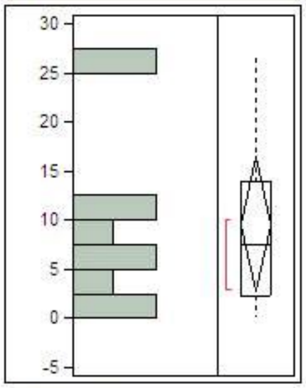
Variable	by Variable	Correlation	Count	Signif Prob
% Catch Developed	D50	-0.4846	16	0.0571
% Local Developed	D50	-0.1451	16	0.5920
% Local Developed	% Catch Developed	0.1540	18	0.5418
Bed Material	D50	0.1497	16	0.5799
Bed Material	% Catch Developed	-0.0678	18	0.7891
Bed Material	% Local Developed	-0.2196	18	0.3812
Incision	D50	-0.4620	16	0.0716
Incision	% Catch Developed	0.1619	18	0.5209
Incision	% Local Developed	-0.0139	18	0.9562
Incision	Bed Material	-0.0852	18	0.7369
Instability	D50	-0.5224	16	0.0379*
Instability	% Catch Developed	0.2012	18	0.4234
Instability	% Local Developed	0.0340	18	0.8934
Instability	Bed Material	-0.1330	18	0.5987
Instability	Incision	0.2682	18	0.2818
Vegetation	D50	-0.3511	16	0.1824
Vegetation	% Catch Developed	-0.0804	18	0.7512
Vegetation	% Local Developed	-0.0120	18	0.9624
Vegetation	Bed Material	0.2455	18	0.3262
Vegetation	Incision	-0.1421	18	0.5737
Vegetation	Instability	0.0972	18	0.7011
Bank Accretion	D50	0.4152	16	0.1098
Bank Accretion	% Catch Developed	-0.3374	18	0.1709
Bank Accretion	% Local Developed	-0.3485	18	0.1564
Bank Accretion	Bed Material	0.0318	18	0.9004
Bank Accretion	Incision	-0.1388	18	0.5829
Bank Accretion	Instability	0.2014	18	0.4228
Bank Accretion	Vegetation	-0.1400	18	0.5794
Slope	D50	-0.2221	16	0.4084
Slope	% Catch Developed	0.1128	18	0.6558
Slope	% Local Developed	0.1251	18	0.6208
Slope	Bed Material	-0.1360	18	0.5905
Slope	Incision	0.5797	18	0.0117*
Slope	Instability	0.0377	18	0.8821
Slope	Vegetation	-0.0723	18	0.7755
Slope	Bank Accretion	0.0803	18	0.7514
SCE	D50	-0.3630	16	0.1670
SCE	% Catch Developed	0.1869	18	0.4578
SCE	% Local Developed	0.1449	18	0.5661
SCE	Bed Material	-0.0456	18	0.8575
SCE	Incision	0.1199	18	0.6357
SCE	Instability	0.7223	18	0.0007*
SCE	Vegetation	0.0119	18	0.9626
SCE	Bank Accretion	0.1271	18	0.6153
SCE	Slope	0.2821	18	0.2568
RGA Score	D50	-0.3660	16	0.1633
RGA Score	% Catch Developed	-0.0899	18	0.7226
RGA Score	% Local Developed	-0.0892	18	0.7250
RGA Score	Bed Material	0.2315	18	0.3554
RGA Score	Incision	0.1176	18	0.6422
RGA Score	Instability	0.8222	18	<.0001*
RGA Score	Vegetation	0.3940	18	0.1057
RGA Score	Bank Accretion	0.4400	18	0.0676
RGA Score	Slope	0.0629	18	0.8042
RGA Score	SCE	0.6835	18	0.0018*



Appendix H Distributions of d50 Particle Sizes in Low, Medium and High Development Watersheds (in mm)

Distributions

D50



Quantiles

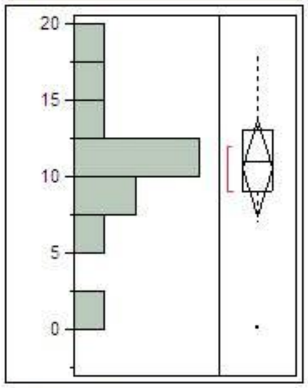
100.0%	maximum	27.000
99.5%		27.000
97.5%		27.000
90.0%		26.900
75.0%	quartile	14.000
50.0%	median	7.500
25.0%	quartile	2.258
10.0%		0.033
2.5%		0.033
0.5%		0.033
0.0%	minimum	0.033

Moments

Mean	9.6066
Std Dev	9.5982321
Std Err Mean	3.0352275
upper 95% Mean	16.472762
lower 95% Mean	2.7404384
N	10

Distributions

D50



Quantiles

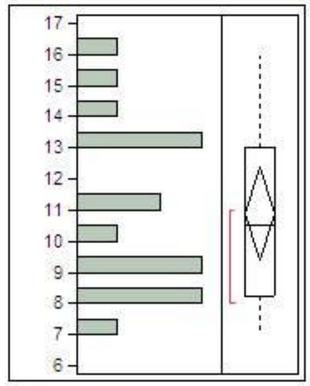
100.0%	maximum	18.000
99.5%		18.000
97.5%		18.000
90.0%		17.600
75.0%	quartile	13.000
50.0%	median	11.000
25.0%	quartile	9.000
10.0%		1.426
2.5%		0.033
0.5%		0.033
0.0%	minimum	0.033

Moments

Mean	10.548455
Std Dev	4.71203
Std Err Mean	1.4207305
upper 95% Mean	13.714039
lower 95% Mean	7.3828697
N	11

Distributions

D50



Quantiles

100.0%	maximum	16.000
99.5%		16.000
97.5%		16.000
90.0%		15.300
75.0%	quartile	13.000
50.0%	median	10.500
25.0%	quartile	8.250
10.0%		7.700
2.5%		7.000
0.5%		7.000
0.0%	minimum	7.000

Moments

Mean	10.875
Std Dev	2.8017851
Std Err Mean	0.7004463
upper 95% Mean	12.367966
lower 95% Mean	9.3820341
N	16

Vita

In Philadelphia, Pennsylvania, Francis Bartholomew (Bart) Keaney was born and raised. He received his primary education in Quaker schools, during which time he was recognized as a National Merit Scholarship Program Commended Scholar. He completed undergraduate study at Temple University in 2007, earning a Bachelor of Science in Environmental Engineering Technology. While at Temple, he was recognized on the College of Engineering Dean's List, spent several semesters working as an undergraduate research assistant in Dr. Adrienne Cooper's environmental chemistry lab and participated on multidisciplinary team of students developing methods of distributed-source green energy production in the Dominican Republic. He served as president of Students for Environmental Action, as well as representing that club in the Student Government Association.

He completed one semester of graduate course work at Temple University under Dr. Qiang He. He then followed Dr. He in a move to the University of Tennessee in Knoxville. From that school, in the fall of 2009, he earned a Master of Science in Environmental Engineering.